Ports infrastructure and exports, evidence from Japan 2011 Tsunami

Masashige Hamano* and Wessel N. Vermeulen†

2016

Abstract

The paper explores the implication of internal trade related costs. We extend the standard trade model with heterogenous firms to have a multiple port structure where exporting is subject to port specific local transportation costs and port specific fixed export costs as well as international bilateral trade costs. We derive a gravity equation with multiple ports and show that gravity distortion due to firm heterogeneity is conditional on port comparative advantage and resulting substitution of export across differentiated ports. Finally, we test the prediction of the model with Japanese custom data and detect a port substitution following the 2011 tsunami disaster.

Keywords: firm heterogeneity, extensive margins, transportation costs, fixed costs JEL classification:

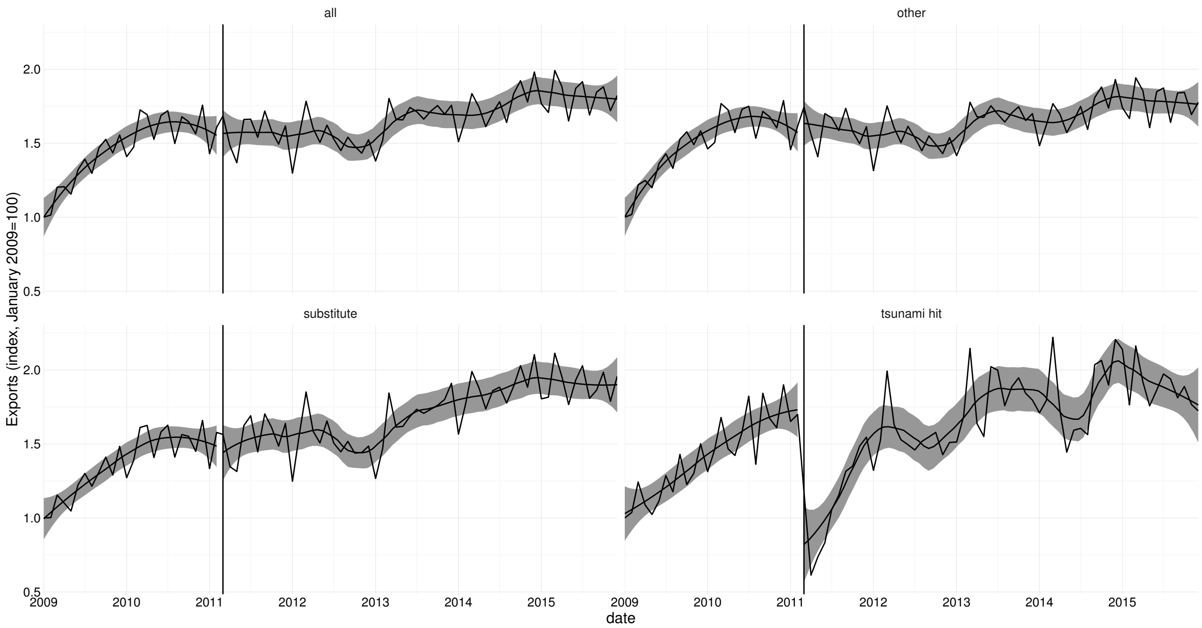
1 Introduction

In this paper we contribute to the growing literature on internal barriers to international trade. We do this in two ways. Firstly, we develop a model, based on trade model with heterogenous firms, that makes explicit the dynamics that can exist in an economy when firms can have multiple routes to exports, say to different ports. Each route will have a particular combination of fixed and variable cost. A profit optimizing firm will minimize the cost of exports. We derive the implications for trade when fixed and variable costs change for one port and how this affect the trade for other ports. We hereby extend the gravity framework in heterogenous firms model with internal trade costs and explicit interaction effects between trade routes. Secondly, we test the prediction of the theoretical

*Sophia University and University of Luxembourg, CREA. Contact address: Sophia University, Yotsuya Campus ,2 go-kan, 1123, 7-1 Kioi-cho, Chiyoda-ku Tokyo 102-8554 Japan. E-mail : masahige.hamano@gmail.com

†Newcastle University

Figure 1: Aggregate exports from Japan to rest of the world



model with Japanese custom data, in particular we explore the implication of tsunami shock induced by the March 2011 earthquake in Tohoku region on each custom's export flow.

The growing interest to internal barriers to trade comes when external barriers to trade have fallen dramatically over the last decades, and more progress and impact can be achieved by focusing on within country barriers relative to between countries. Our paper informs what mechanisms are in play when policy makers decide to invest in trade infrastructure in one location, leaving other locations unchanged but still impacted. One can also think of port competition in the European union, where the internal borders have disappeared but ports may still be fiercely competing for trade and national economies can choose to invest in the infrastructure that facilitates the trade.

The disaster that Japan experienced is interesting from an economic point of view because it is not immediately visible in aggregate statistics. Figure 1 makes this clear. The thin fluctuating line gives the aggregate series of the dataset we are using here, as an index. The smooth line uses a standard smoothing procedure and is separately estimated for the period before and after the tsunami, with the shaded area representing a 95% confidence interval.

The ports are divided in three groups on top of the aggregate of the three groups. We define tsunami hit ports as those that were directly struct by the tsunami, the substitute as those that were 'relatively' close and all other ports (the groups are further explained in the empirical section). The effect of the tsunami is clearly visible for the ports that were directly hit, but hardly visible in the aggregate or the other other two groups. One potential reason for this could be that the ports hit by the tsunami were of negligible size initially. However, this is not the case. The aggregate of the ports hit by the tsunami were about a tenth of the size of the aggregate of the substitutes. Given that former lost about 75% of its trade, we should find some effect for the substitutes if our model were true. The standard fluctuation that is present from one month to the other hides this effect and we will use more sophisticated econometric techniques in this paper to uncover the effect of the tsunami on ports that were hit and functioned as substitutes.

We build a model of multiple ports based on Melitz (2003). The number of ports in a country is exogenously given and ports from which heterogeneous firms export are differentiated with respect to their internal distance and specific fixed export costs. Some ports have their advantage in terms of proximity to firms' location while others are advantaged in terms of lower fixed export costs. Thus trade facilitation of each port depends on its comparative advantage between port specific local transportation costs and port specific fixed export costs. It is shown that exports are shipped through multiple ports in equilibrium as long as there exist such a comparative advantage structure. All results collapse, however, by imposing absolute advantage for a specific port and we revisit the case of single port as in a standard Melitz-type model.

Motivated from empirical point of view, we consider a special case in which firms are facing a choice to export between two competing ports that have different infrastructures. The other alternative ports are just considered too far to export from due to infinitely high internal trade cost. In the presence of such a port comparative advantage, we establish port specific gravity equation and decompose trade flow of each port into extensive margins, intensive margins and composition margins of export as in Chaney (2008). A rise in bilateral transportation costs, which captures "distance" between countries, induces changes in each margins and results in a decrease in aggregate trade flow whose sensitivity depends on the extent of firm heterogeneity in the economy. The gravity is thus "distorted" (Chaney, 2008) due to the inclusion of firm heterogeneity. On the other hand, we show that the aggregate trade flow is also subject to local transportation costs, that proxy the distance between ports and firms' location. A rise in internal trade cost until a specific port induces a decrease in exports from that port while exports from the another competing port increases. Through such a substitution of export from one port to the another, aggregate exports of a country fluctuate to some extent. "Internal" gravity matters for aggregate trade flow, therefore. Changes in port specific fixed export costs also induces a similar substitution across ports, however, with different magnitude depending on comparative advantage of port.

We test the predictions on how ports are effected by the a change in fixed, and whether there is a spill-over to other ports with a Japanese dataset. We have for each port monthly data of exports from 2009 onwards. We calculate trade margins for each the port using a 9-digit product categorisation, at the monthly frequency. We then exploit the 2011 great Japanese earthquake as an exogenous change in internal trade costs that affected some ports, but not others. The tsunami that was caused by the earthquake deep under the sea off the coast of north-eastern Honshu destructed a number of ports that were directly in the line of the Tsunami. Other ports, further away or protected by natural bays were not affected. We find the opposing effects on the two types of ports on the value of trade. When decomposing the trade flow in intensive and extensive margins we find that the effect mostly follows from the extensive margins of trade, as predicted by the theory. We find that the substitution ports may have gained up to 30 percentage additional trade for some months and gained 3 percentage points in their extensive margin, representing a 10 percent increase from their pre-disaster margins.

As stated, our paper fits in a new and growing literature in trade that focusses on the role of within-country barriers to trade (Hillberry and Hummels, 2007; Portugal-Perez and Wilson, 2012; Atkin and Donaldson, 2015). What we bring to this literature is a new extention to a familiar model of trade that can be directly brought to datasets such the one we present here. Exogenous changes in fixed costs are often use as identification strategies. We offer a credible case where fixed costs were exogenously changed (for an extended period).

Although we do use a natural disaster for our identification strategy our focus is different from many paper in the literature on the economic consequences of natural disasters. Firstly, we are particularly interested on the effect of areas that were not hit by the disaster. Secondly, we argue that the destruction was limited to the coastal in north eastern Honshu, and did not extend far inland. In a sense, the destruction was specifically targeted at ports. Despite the dramatic images of inundated coastal villages, these presented local extremes that should not be hold as representative for the entire region. Major earthquakes, such as one around Kobe in 1995, have been exploited to understand how such disasters propagate through an economy (Matthew A. Cole et al., 2015; Hosono et al., 2012; Tanaka, 2015). First analysis on the the 2011 disaster, in particular with respect to the consequences on the energy market following the failure of the Fukushima-Dashi Nuclear power plant has started (Economics of Energy & Environmental Policy, 2015). We are unaware of any research that has exploited the events to analyse internal barriers to trade.

2 The model

There are N number of countries in the world. In a country n, there are multiple ports whose number is exogenously given by K_n. The population and labor supply is also exogenously given by L_n. In each country, sector 0 provides homogenous goods which serve as a numeraire and traded worldwide without any transportation cost while other sectors (whose total number is amount to H) are made of differentiated goods. Firms, that are heterogenous in terms of their specific productivity level, are monopolistically competitive in differentiated sectors. Our model departs from Chaney (2008) by allowing firms to choose a specific port in exporting.

2.1 Households

Households of a typical country get a utility in consuming the set of differentiated product varieties in each sector, Ω_h, as well as homogenous goods:

$$C = c_0^{\alpha_0} \prod_{h=1}^{H} \left(\int_{\Omega_h} \left(q\left(\omega\right) c\left(\omega\right) \right)^{1-\frac{1}{\sigma_h}} d\omega \right)^{\frac{\alpha_h}{1-\frac{1}{\sigma_h}}},$$

where c_0 is the consumption of homogenous goods. $c\left(\omega\right)$ is the consumption of a particular product variety indexed by ω which is either produced locally or imported. $q\left(\omega\right)$ is the "quality" of that goods which is defined as an exogenous demand shifter. The elasticity of substitution of product varieties in each sector is given by σ_h (> 1). The expenditure weight on homogenous goods is given by α_0 and that on goods in sector h is given by α_h.

2.2 Ports and Firms

Firms are assumed to be heterogenous in terms of their specific labor productivity level, φ, and are facing the following choice: export or not export, and if export, export from which port. Production involves only labor as input. Exporting from a origin country i to a destination country j requires port specific fixed costs, f_{ijk}^h, and a port specific iceberg type of local transportation costs within country, μ_{ijk}^h (> 1), as well as an iceberg type of bilateral trade costs, $\tau_{ij}^h (> 1)$. From now on, we focus on a firm with a specific productivity, φ and drop sector index h when there is no room for confusion.

Total costs in producing y unit of a good and exporting these goods to country j from country i of port k is thus given by

$$TC_{ijk}\left(\varphi\right) = \frac{w_i \mu_{ijk} \tau_{ij}}{\varphi q_{ij} Z_i} y + f_{ijk},$$

where w_i denotes real wages in country i which is found to be 1 due to our choice of numeraire. q_{ij} is origin-destination (-sector) specific demand shifter.[1] Z_i represents the level of labor productivity which is common for all firms in country i.

2.3 Demand for differentiated goods

Due to the monopolistic competition, production scale is determined by demand. The demand addressed to the firm that has a productivity level φ from a destination country

[1]We do not model the endogenous product quality choice by firm and consider it as exogenous for the sake of simplicity. See Feenstra and Romalis (2014) for instance about its endogenous determination mechanism based on Melitz (2003).

j is given by

$$c_{ijk}(\varphi) = q_{ij}^{\sigma-1}\left(\frac{p_{ijk}(\varphi)}{P_j}\right)^{-\sigma}\alpha C_j, \tag{1}$$

with

$$p_{ijk}(\varphi) = \frac{\sigma}{\sigma-1}\frac{w_i\mu_{ijk}\tau_{ij}}{\varphi q_{ij}Z_i}. \tag{2}$$

In the above expression, P_j is the ideal price index for a particular sector in country j.

If the firm exports from port k, dividends are given by $d_{ijk}(\varphi) = p_{ijk}(\varphi)\, c_{ijk}(\varphi) - TC_{ijk}(\varphi)$ from exporting. Plugging the demand (1) and optimal price (2), we get

$$d_{ijk}(\varphi) = \frac{1}{\sigma}\left(\frac{p_{ijk}(\varphi)/q_{ij}}{P_j}\right)^{1-\sigma}\alpha Y_j - f_{ijk} \tag{3}$$

where Y_j is total income or total expenditure of country j. Namely, $Y_j = P_jC_j = w_jL_j(1+d)$ where d is the dividends from a global mutual fund that corrects and distributes dividends from all over the world. Following Chaney (2008), we assume that the share of dividends is proportional to the total labor income of each country and that the potential number of entrants in exporting market is proportional to the total labor income in the country, w_jL_j. Specifically, the latter assumption simplifies the analysis by abstracting free entry of firms.

2.4 Decision to Export and Port Choice

A cutoff productivity level $\overline{\varphi}_{ijk}$ above which firms export is determined by $d_{ijk}\left(\overline{\varphi}_{ijk}\right) = 0$ for each port. By solving the above zero-profit-cutoff (ZCP) condition, we have:

$$\overline{\varphi}_{ijk} = \lambda_1\left(\frac{w_i\mu_{ijk}\tau_{ij}}{q_{ij}Z_iP_j}\right)\left(\frac{f_{ijk}}{Y_j}\right)^{\frac{1}{\sigma-1}}, \tag{4}$$

where $\lambda_1 = (\sigma/\alpha)^{\frac{1}{\sigma-1}}[\sigma/(\sigma-1)]$. Note that the cutoff level is port specific due to port specific local transportation costs μ_{ijk} and port specific fixed export costs f_{ijk}.

Having computed the cutoff productivity level for each port, we rank them according to their size as

$$\overline{\varphi}_{ijK_n} < \overline{\varphi}_{ijK_n-1} < ... < \overline{\varphi}_{ij2} < \overline{\varphi}_{ij1} \tag{5}$$

For any pair of cutoff productivity level $\overline{\varphi}_{ijk}$ and $\overline{\varphi}_{ijs}$ with $k = 2...K_n$ with $k > s$ we can define another cutoff productivity level $\overline{\varphi}_{ijks}$ with which firms become indifferent in exporting from either port as $d_{ijk}\left(\overline{\varphi}_{ijks}\right) = d_{ijs}\left(\overline{\varphi}_{ijks}\right)$. Solving this even profit cutoff condition (EPC), we have

$$\overline{\varphi}_{ijks} = \lambda_1 \left(\frac{w_i \tau_{ij}}{q_{ij} Z_i P_j} \right) \left[\frac{f_{ijs} - f_{ijk}}{Y_j \left(\mu_{ijs}^{-(\sigma-1)} - \mu_{ijk}^{-(\sigma-1)} \right)} \right]^{\frac{1}{\sigma-1}}. \tag{6}$$

Two competing ports k and s through their cutoff productivity level $\overline{\varphi}_{ijk}$ and $\overline{\varphi}_{ijs}$ have different port specific features with respect to local transportation costs and fixed export costs. We assume that port s is more efficient in terms of local transportation costs while port s is less efficient in terms of its fixed export costs than port k. Under such a condition, firms are spread into multiple ports in exporting. Precisely speaking, by assuming *the port comparative advantage* as $f_{ijs}/f_{ijk} > (\mu_{ijs}/\mu_{ijk})^{1-\sigma} > 1$, we establish the following proposition.

Proposition 1 .

Under $f_{ijs}/f_{ijk} > (\mu_{ijs}/\mu_{ijk})^{1-\sigma} > 1$ *for* $k = 2...K_n$ *with* $k > s$*, we have* $\overline{\varphi}_{ijk} < \overline{\varphi}_{ijs} < \overline{\varphi}_{ijks}$*. In this case, firms with* $\overline{\varphi}_{ijks} < \varphi$ *prefer to export from port* s *while firms with* $\varphi < \overline{\varphi}_{ijks}$ *prefer to export from port* k *and multiple ports are in action.*

Proof. See Appendix. ■

When $(\mu_{ijs}/\mu_{ijk})^{1-\sigma} > 1$, marginal increase in profits of exporting from port s is higher than that from port k for firms with $\overline{\varphi}_{ijks} < \varphi$. Therefore, exporters spread into either port with which they earn higher exporting profits. Having established even profit cutoff productivity levels for any pairs of port provided the ranking of zero profit cutoff productivity levels for each port as (5), the firm with φ eventually chooses to export from one specific port k^* that maximizes its exporting profits $d_{ijk^*}(\varphi_{ijk^*})$. See also Figure **??** where we provide a specific case with $K_n = 3$ and $\overline{\varphi}_{32} < \overline{\varphi}_{31} < \overline{\varphi}_{21}$.

When $(\mu_{ijs}/\mu_{ijk})^{1-\sigma} < 1$ however, firms absolutely prefer to export from port k independent of their productivity level and we have the following corollary.

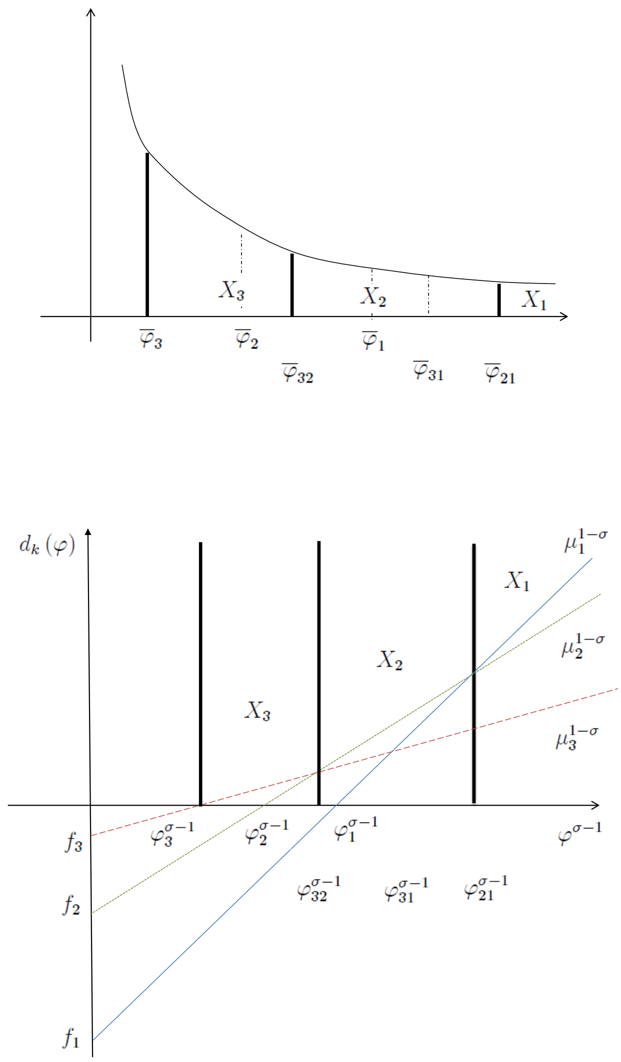
Corollary 1 .

When $\mu_{ij1} > \mu_{ij2} > ... > \mu_{ijK_n-1} > \mu_{ijK_n}$*, all exporters export from port* K_n*.*

By removing the port comparative advantage, the port K_n has now absolute advantage in both fixed export costs and local transportation costs, which results in attracting all local exporters.

Having established the above export decision and port decision, we can compute the ideal price index in country j as

Figure 2: Multiple Port in Action ($K_n = 3$ and $\overline{\varphi}_3 2 < \overline{\varphi}_3 1 < \overline{\varphi}_2 1$)



$$\left(\frac{\sigma-1}{\sigma}P_j\right)^{1-\sigma}$$
$$= \sum_{m=1}^{N} w_m L_m \left[\int_{\overline{\varphi}_{mjK_n}}^{\overline{\varphi}_{mjK_nK_n-1}} \left(\frac{w_m \mu_{mjK_n} \tau_{mj}}{q_{mj} Z_m}\right)^{1-\sigma} dG(\varphi) + ... + \int_{\overline{\varphi}_{mj21}}^{\infty} \left(\frac{w_m \mu_{mj1} \tau_{mj}}{q_{mj} Z_m}\right)^{1-\sigma} dG(\varphi)\right] \tag{7}$$

2.5 Core (δ) and Peripheral (γ) Port

In order to solve the model, we assume Pareto distribution for firm specific productivity level as $G(\varphi) = 1 - \varphi^{-\kappa}$ where κ ($> \sigma - 1$) is the shaping parameter of distribution. When κ increases, firms are more concentrated at its minimum level of productivity, which we set as unity. Also, we assume that $\mu_{ijK_n-2} = \infty$ which results in $\overline{\varphi}_{ijK_n-2} = \infty$. The above condition eliminates the possibility of exporting from ports with $k \geq K_n - 2$ which are "too far" leaving the possibility to firms to export either from port K_n or $K_n - 1$. This latter assumption is motivated from practical point of view that firms are facing the choice between two alternatives of ports in exporting. From now on, port $K_n - 1$ and port K_n are designated as port γ and port δ, respectively. γ-port is considered as "peripheral" port since it allows a limited number of firms at the higher end of distribution to export while δ-port is considered as "core" port attracting the majority of firms at the lower end of distribution.

Provided the above distribution and plugging the cutoff levels (4) and (6) in the ideal price index (7) together with the definition of core (δ) and peripheral (γ) port, we have

$$P_j = \lambda_2 Y_j^{\frac{1}{\kappa} - \frac{1}{\sigma-1}} \vartheta_j,$$

where $\lambda_2 = [(1+d)/Y][\kappa - (\sigma-1)/\kappa][\sigma/(\sigma-1)]^{\kappa}(\sigma/\alpha)^{\frac{\kappa}{\sigma-1}-1}$ and

$$\vartheta_j^{-k} = \sum_{m=1}^{N} \frac{Y_m}{Y} \left(\frac{w_m \tau_{mj}}{q_{mj} Z_m}\right)^{-\kappa} \left[f_{mj\delta}^{-\left(\frac{\kappa}{\sigma-1}-1\right)} \mu_{mj\delta}^{-\kappa} + (f_{mj\gamma} - f_{mj\delta})^{-\left(\frac{\kappa}{\sigma-1}-1\right)} \left(\mu_{mj\gamma}^{-(\sigma-1)} - \mu_{mj\delta}^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}}\right].$$

Thus ϑ_j is the weighted average of origin and destination specific characteristics capturing the "remoteness" of country j from the rest of the world. Different from the expression in Chaney (2008), however, the term includes efficiency of ports in each county in the square bracket. Conventionally, the impact stemming from changes in bilateral trade cost of country m is considered to be negligible in ϑ_j. Similarly, we assume that any changes in port specific costs are negligible as $\partial\vartheta_j/\partial f_{mj\gamma} = \partial\vartheta_j/\partial f_{mj\delta} = \partial\vartheta_j/\partial\mu_{mj\gamma} = \partial\vartheta_j/\partial\mu_{mj\delta} = 0$.

With the above closed form solution, exporting sales of firm φ that exports from country i to j, $x_{ijk}(\varphi) = p_{ijk}(\varphi)\, y_{ijk}(\varphi)$ with $k = \gamma$ or δ, can be expressed as

$$x_{ij\gamma}(\varphi) = \lambda_3 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \mu_{ij\gamma} \tau_{ij}}{q_{ij} Z_i \vartheta_j}\right)^{1-\sigma} \varphi^{\sigma-1}, \text{ if } \overline{\varphi}_{ij\delta\gamma} < \varphi,$$
$$x_{ij\delta}(\varphi) = \lambda_3 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \mu_{ij\delta} \tau_{ij}}{q_{ij} Z_i \vartheta_j}\right)^{1-\sigma} \varphi^{\sigma-1}, \text{ if } \overline{\varphi}_{ij\delta} < \varphi < \overline{\varphi}_{ij\delta\gamma},$$
$$0 \text{ otherwise,} \tag{8}$$

where $\lambda_3 = \sigma \lambda_4^{1-\sigma}$ and $\lambda_4^{\kappa} = [1/(1+d)]\,[\kappa/\kappa - (\sigma-1)]\,(\sigma/\alpha)$. Cutoff productivity levels are also rewritten as

$$\overline{\varphi}_{ij\delta} = \lambda_4 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \mu_{ij\delta} \tau_{ij}}{q_{ij} Z_i \vartheta_j}\right) f_{ij\delta}^{\frac{1}{\sigma-1}}$$

$$\overline{\varphi}_{ij\delta\gamma} = \lambda_4 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \tau_{ij}}{q_{ij} Z_i \vartheta_j}\right) \left(\frac{f_{ij\gamma} - f_{ij\delta}}{\mu_{ij\gamma}^{-(\sigma-1)} - \mu_{ij\delta}^{-(\sigma-1)}}\right)^{\frac{1}{\sigma-1}}$$

Finally we have $Y_j = (1+d)\, w_i L_i$ where d is constant.

2.6 Gravity

Exports from peripheral port γ is given by $X_{ij\gamma} = w_i L_i \int_{\overline{\varphi}_{ij\delta\gamma}}^{\infty} x_{ij\gamma}(\varphi)\, dG(\varphi)$ while those from core port δ is given by $X_{ij\delta} = w_i L_i \int_{\overline{\varphi}_{ij\delta}}^{\overline{\varphi}_{ij\delta\gamma}} x_{ij\delta}(\varphi)\, dG(\varphi)$. Thanks to the closed form expression, we derive gravity equation from each port. Exports from port γ is given by

$$X_{ij\gamma} = \alpha \frac{Y_i Y_j}{Y} \left(\frac{w_i \tau_{ij}}{q_{ij} Z_i \vartheta_j}\right)^{-\kappa} \mu_{ij\gamma}^{-(\sigma-1)} \left(\mu_{ij\gamma}^{-(\sigma-1)} - \mu_{ij\delta}^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}-1} \left(f_{ij\gamma} - f_{ij\delta}\right)^{-\left(\frac{\kappa}{\sigma-1}-1\right)}. \tag{9}$$

Exports from port δ is given by

$$X_{ij\delta} = \alpha \frac{Y_i Y_j}{Y} \left(\frac{w_i \tau_{ij}}{q_{ij} Z_i \vartheta_j}\right)^{-\kappa}$$
$$\left[\mu_{ij\delta}^{-\kappa} f_{ij\delta}^{-\left(\frac{\kappa}{\sigma-1}-1\right)} - \mu_{ij\delta}^{-(\sigma-1)} \left(\mu_{ij\gamma}^{-(\sigma-1)} - \mu_{ij\delta}^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}-1} \left(f_{ij\gamma} - f_{ij\delta}\right)^{-\left(\frac{\kappa}{\sigma-1}-1\right)}\right]. \tag{10}$$

Total exports from country i to j is thus given by

$$X_{ij} = X_{ij\delta} + X_{ij\gamma}$$
$$= \alpha \frac{Y_i Y_j}{Y} \left(\frac{w_i \tau_{ij}}{q_{ij} Z_i \vartheta_j}\right)^{-\kappa} \left[\mu_{ij\delta}^{-\kappa} f_{ij\delta}^{-\left(\frac{\kappa}{\sigma-1}-1\right)} - \left(\mu_{ij\gamma}^{-(\sigma-1)} - \mu_{ij\delta}^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}} \left(f_{ij\gamma} - f_{ij\delta}\right)^{-\left(\frac{\kappa}{\sigma-1}-1\right)}\right].$$

Note that by abandoning the assumption of , $\mu_{ij\delta} > \mu_{ij\gamma}$, all firms export from core port δ. and the expression collapses to a similar one as in Chaney (2008).

2.7 Margin Decomposition

In this subsection, we discuss the decomposition of trade flow as in the literature (Chaney 2008, Head and Mayer 2014). For the sake of notational simplicity we drop origin and destination index, i and j when there is no room for confusion. Export flow from each port can be decomposed as $X_\gamma = N_{X\gamma}\widetilde{x}_\gamma$ and $X_\delta = N_{X\delta}\widetilde{x}_\delta$ where $N_{X\gamma} = wL\left(1 - G(\overline{\varphi}_{\delta\gamma})\right)$ and $N_{X\delta} = wL\left(G(\overline{\varphi}_{\delta\gamma}) - G(\overline{\varphi}_{\delta})\right)$ represent the number exporters and $\widetilde{x}_\gamma = \left[\int_{\overline{\varphi}_{\delta\gamma}}^{\infty} x_\gamma(\varphi)\, dG(\varphi) / \left(1 - G(\overline{\varphi}_{\delta\gamma})\right)\right]$ and $\widetilde{x}_\delta = \left[\int_{\overline{\varphi}_{\delta}}^{\overline{\varphi}_{\delta\gamma}} x_\delta(\varphi)\, dG(\varphi) / \left(G(\overline{\varphi}_{\delta\gamma}) - G(\overline{\varphi}_{\delta})\right)\right]$ capture the average export flow among these exporters from port γ and port δ, respectively. The number of exporters is called "extensive margins". The average export flow is further decomposed into "intensive margins", i.e. changes in average export scale given a cutoff productivity level and "composition margins", i.e., remaining impact on average export flow induced by changes in cutoff productivity level. We provide the result of comparative statics analysis of each component in total export flow induced by exogenous changes in iceberg type of bilateral trade costs τ, aggregate labor productivity level Z_i, country and destination specific demand shifter q, port specific fixed export costs f_k and port specific local transportation costs μ_k. Namely, we compute

$$\frac{d\ln X_k}{d\ln v} = \frac{d\ln N_{Xk}}{d\ln v} + \frac{d\ln \widetilde{x}_k}{d\ln v},$$

where $k = \gamma$ or δ, $v = \tau$, Z_i, q, f_k, μ_k and $d\ln\widetilde{x}_k/d\ln v$ includes both intensive margins and composition margins. Table 1 presents elasticities of each margin as well as of total exports with respect to each exogenous shock for each export from port γ and port δ, respectively. In Table 1, $\overline{f}_\gamma$, $\overline{f}_\delta$, $\overline{\mu}_\gamma$ and $\overline{\mu}_\delta$ represent the steady state value of port specific fixed costs and local transportation costs. Capital letters in Table 1 are a function of parameters given these steady state values which are detailed in Table 2.

As shown in Table 1, shocks that are independent of port characteristics, namely τ, Z_i and q, have exactly the same impact on exports from port γ, X_γ and those from port δ, X_δ as well as for each margin. Such a symmetry across two ports is true for margin decomposition induced by other two shocks, Z_i and q. For instance, when bilateral trade costs τ rises, extensive margins decrease with the elasticity of $-\kappa$ while average export remains unchanged because of reduced intensive margins by $-(\sigma - 1)$ but expanding export of surviving exporters by $\sigma - 1$ (composition changes). The result is exactly the same for port γ and port δ. The same expression is provided by Chaney (2008) with a single port case.

Port specific shocks, however, have dramatically different implications across ports. On the one hand, with respect to trade flow X_γ, when fixed export costs f_γ increase,

Table 1: Margins Decomposition

Elasticities	E.M	I.M	C.M	Total
$\frac{d\ln X_\gamma}{d\ln\tau}$	$-\kappa$	$-(\sigma-1)$	$\sigma-1$	$-\kappa$
$\frac{d\ln X_\gamma}{d\ln Z_i}$	κ	$\sigma-1$	$-(\sigma-1)$	κ
$\frac{d\ln X_\gamma}{d\ln q}$	κ	$\sigma-1$	$-(\sigma-1)$	κ
$\frac{d\ln X_\gamma}{d\ln f_\gamma}$	$-\frac{\kappa}{\sigma-1}\mathsf{F}_\gamma$	0	F_γ	$-\left(\frac{\kappa}{\sigma-1}-1\right)\mathsf{F}_\gamma$
$\frac{d\ln X_\gamma}{d\ln f_\delta}$	$\frac{\kappa}{\sigma-1}\mathsf{F}_\delta$	0	$-\mathsf{F}_\delta$	$\left(\frac{\kappa}{\sigma-1}-1\right)\mathsf{F}_\delta$
$\frac{d\ln X_\gamma}{d\ln \mu_\gamma}$	$-\kappa\mathsf{U}_\gamma$	$-(\sigma-1)$	$(\sigma-1)\mathsf{U}_\gamma$	$-\left[\kappa-(\sigma-1)\right]\mathsf{U}_\gamma-(\sigma-1)$
$\frac{d\ln X_\gamma}{d\ln \mu_\delta}$	$\kappa\mathsf{U}_\delta$	0	$-(\sigma-1)\mathsf{U}_\delta$	$\left[\kappa-(\sigma-1)\right]\mathsf{U}_\delta$
$\frac{d\ln X_\delta}{d\ln\tau}$	$-\kappa$	$-(\sigma-1)$	$\sigma-1$	$-\kappa$
$\frac{d\ln X_\delta}{d\ln Z_i}$	κ	$\sigma-1$	$-(\sigma-1)$	κ
$\frac{d\ln X_\delta}{d\ln q}$	κ	$\sigma-1$	$-(\sigma-1)$	κ
$\frac{d\ln X_\delta}{d\ln f_\delta}$	$-\frac{\kappa}{\sigma-1}\Gamma_\delta$	0	$-\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_\delta+\frac{\kappa}{\sigma-1}\Gamma_\delta$	$-\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_\delta$
$\frac{d\ln X_\delta}{d\ln f_\gamma}$	$\frac{\kappa}{\sigma-1}\Gamma_\gamma$	0	$\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_\gamma-\frac{\kappa}{\sigma-1}\Gamma_\gamma$	$\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_\gamma$
$\frac{d\ln X_\delta}{d\ln \mu_\delta}$	$-\kappa\Theta_\delta$	$-(\sigma-1)$	$-\left[\kappa-(\sigma-1)\right]\Lambda_\delta+\kappa\Theta_\delta$	$-\left[\kappa-(\sigma-1)\right]\Lambda_\delta-(\sigma-1)$
$\frac{d\ln X_\delta}{d\ln \mu_\gamma}$	$\kappa\Theta_\gamma$	0	$\left[\kappa-(\sigma-1)\right]\Lambda_\gamma-\kappa\Theta_\gamma$	$\left[\kappa-(\sigma-1)\right]\Lambda_\gamma$

Table 2: Parameters

$\left(\overline{f}_\gamma/\overline{f}_\delta\right)^{\frac{1}{\sigma-1}}>\overline{\mu}_\delta/\overline{\mu}_\gamma>1$	
$\mathsf{F}_\gamma=\frac{1}{1-\frac{\overline{f}_\delta}{\overline{f}_\gamma}}>1$	$\mathsf{F}_\delta=\frac{1}{\frac{\overline{f}_\gamma}{\overline{f}_\delta}-1}>0$
$\mathsf{U}_\gamma=\frac{1}{1-\left(\frac{\overline{\mu}_\gamma}{\overline{\mu}_\delta}\right)^{\sigma-1}}>1$	$\mathsf{U}_\delta=\frac{1}{\left(\frac{\overline{\mu}_\delta}{\overline{\mu}_\gamma}\right)^{\sigma-1}-1}>0$
$\Gamma_\delta=\frac{1}{1-\left(\frac{\mathsf{F}_\delta}{\mathsf{U}_\delta}\right)^{\frac{\kappa}{\sigma-1}}}+\frac{\mathsf{F}_\delta}{\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}}-1}>1$	$\Delta_\delta=\frac{1}{1-\left(\frac{\mathsf{F}_\delta}{\mathsf{U}_\delta}\right)^{\frac{\kappa}{\sigma-1}-1}}+\frac{\mathsf{F}_\delta}{\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}-1}-1}>1$
$\Theta_\delta=\frac{1}{1-\left(\frac{\mathsf{F}_\delta}{\mathsf{U}_\delta}\right)^{\frac{\kappa}{\sigma-1}}}+\frac{\mathsf{U}_\delta}{\left[\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}}-1\right]}>1$	$\Lambda_\delta=\frac{1}{1-\left(\frac{\mathsf{F}_\delta}{\mathsf{U}_\delta}\right)^{\frac{\kappa}{\sigma-1}-1}}+\frac{\mathsf{U}_\delta}{\left[\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}-1}-1\right]}>1$
$\Gamma_\delta>\Gamma_\gamma=\frac{\mathsf{F}_\gamma}{\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}}-1}>0$	$\Delta_\delta>\Delta_\gamma=\frac{\mathsf{F}_\gamma}{\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}-1}-1}>0$
$\Theta_\delta>\Theta_\gamma=\frac{\mathsf{U}_\gamma}{\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}}-1}>0$	$\Lambda_\delta>\Lambda_\gamma=\frac{\mathsf{U}_\gamma}{\left(\frac{\mathsf{U}_\delta}{\mathsf{F}_\delta}\right)^{\frac{\kappa}{\sigma-1}-1}-1}>0$

extensive margins decrease by $-\frac{\kappa}{\sigma-1}\mathsf{F}_\gamma$ and composition margins increase by F_γ This is because a number of less productive firms substitute from peripheral port γ to core port δ in exporting following such a rise in f_γ. Total impact on export X_γ is thus given by $-\left(\frac{\kappa}{\sigma-1}-1\right)\mathsf{F}_\gamma$. Since $\mathsf{F}_\gamma > 1$, both extensive and composition margins are amplified compared to the results obtained in Chaney (2008) who find $-\frac{\kappa}{\sigma-1}$ and 1 for each extensive and composition margin, respectively with a single port. On the other hand, for the same increase in f_γ, extensive margins of competing port δ increase by $\frac{\kappa}{\sigma-1}\Gamma_\gamma$ and composition margins change by $\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_\gamma - \frac{\kappa}{\sigma-1}\Gamma_\gamma$.[2] As a result total exports X_δ increase by $\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_\gamma$. This is due to the above mentioned port substitution effect through which some exporters switch from port γ to port δ in exporting following a rise in fixed export costs in peripheral port γ, f_γ. The similar argument holds for a rise in fixed export costs in core port δ, f_δ with different degree of substitution effect, however.

When local transportation costs until port γ, μ_γ increase, exporters switch from peripheral port γ to core port δ in exporting. As a result, total exports decrease in port γ, X_γ by $-[\kappa-(\sigma-1)]\,\mathsf{U}_\gamma - (\sigma-1)$ while total exports in port δ, X_δ increase by $[\kappa-(\sigma-1)]\,\Lambda_\gamma$. In achieving such a change in X_γ, the number of exporters decrease by $-\kappa\mathsf{U}_\gamma$, intensive margins decrease by $-(\sigma-1)$ while composition margins increase by $(\sigma-1)\mathsf{U}_\gamma$ in peripheral port γ. Since $\mathsf{U}_\gamma > 1$, the size of change of each margin is amplified compared to the case with a rise in international bilateral trade costs τ. And we have a mirror image for each margin in competing port δ where total exports rise by $[\kappa-(\sigma-1)]\,\Lambda_\gamma$ through rise in extensive margins by $\kappa\Theta_\gamma$ and changes in composition margins by $[\kappa-(\sigma-1)]\,\Lambda_\gamma - \kappa\Theta_\gamma$.[3] The similar argument holds for a rise in local transportation costs until core port δ, μ_δ with different degree of substitution effect, however. In the following section, we test the prediction of our model with Japanese data set.

3 Empirics

3.1 Identification strategy

The theoretical model, following equations (9) and (10), suggests the following linearized equation of exports,

$$\ln X_{ijk} = \ln\frac{Y_i}{Y} + \ln\frac{Y_j}{Y} - \kappa\ln\tau_{ij} + \kappa\ln M_i + \kappa\ln\vartheta_j + a\ln\mu_{ijk} + b\ln\mu_{ijl} + c\ln f_{ijk} + d\ln f_{ijl}$$

for exports X from port k in country i to country j. One can add a subscript h for each variable to capture the different effects at the sectoral level. We are particularly

[2]We cannot a priori sign the direction of changes of the composition margins since both end of cutoff simultaneously change. Following a rise in f_γ, a lower end of cutoff productivity level $\overline{\varphi}_\delta$ decreases while a higher end of cutoff productivity level $\overline{\varphi}_{\delta\gamma}$ increases in determination of $\widetilde{x}_\delta$.

[3]Again, we cannot a priori sign the direction of changes of the composition margins since both end of cutoff simultaneously change.

interested identifying the effects of changes in the variable and fixed costs on the export level of ports and their decomposition of the margins. We propose to use the event of the earthquake and tsunami of March 2011 that struck the north-east coast of Japan as an exogenous variation in the cost of bringing goods to port for exports. The tsunami caused destruction for some ports at a specific point in time and therefore leads to the potential of other ports not directly affected by the earthquake and tsunami through the trade spill-over that we modelled.

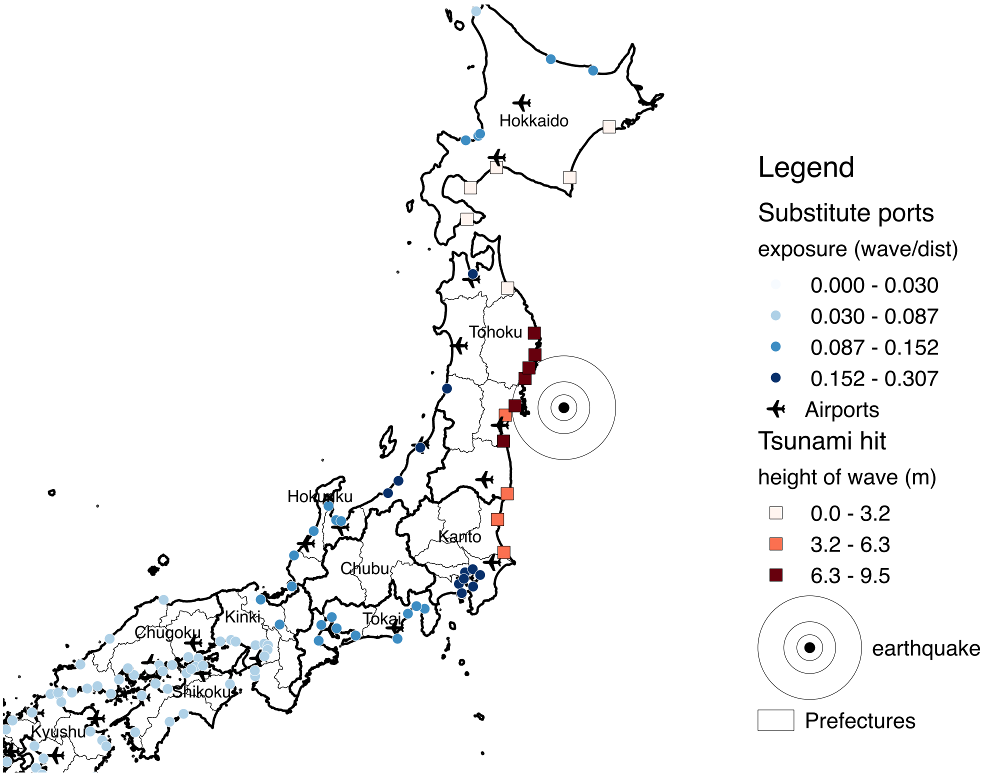
The tsunami was a devastating disaster for the coastal areas of the Tohoku and Kanto regions and around 16.000 people lost there lives. The earthquake of magnitude 9, the strongest recorded for Japan ever, with the epicentre 70km from the coast at a depth of 30km. The earthquake was followed by dozens of smaller quakes of magnitude 6 or higher. Multiple waves hit the shore of north eastern Honshu (Tohoku) with heights up to 6 meters from sea level. The force of the wave made the water surge inland as much as 40 meters above sea level, and in some areas a few kilometers from the coast, although these were local extremes.

Although devastating we argue that the destruction was largely limited to the immediate coastline rather then the hinterlands, as well as limited to the coastline closest to the epicentre and so would have limited direct effects on local business further inland. The tsunami was unexpected and struck ports at the same day. Although Japan is well adapted to the risk of earthquakes and the potential of tsunamis, the precise location, moment and magnitude of such events is for all practical purposes random, while the force of the Tsunami was unprecedented in modern times. This random occurrence of the tsunami makes that ports were randomly assigned this 'treatment'.

Figure 3 presents a map of northern Japan giving an overview of the ports that were hit by the March 2011 Tsunami (squares) and all other ports (circles). For reference, Tokyo is located just south of the tsunami hit ports where a cluster of circles denotes the various ports in the Tokyo area and the Fukushima-Dachi power plant, which failed when it was flooded by the tsunami, is located at the coast of the most southern prefecture of the Tohoku region. From the Japanese Ministry of Industry we have the recorded wave heights for each port. The ports closest to the earthquake epicentre were hit by the highest waves. The color coding of all ports not hit by the tsunami indicates a level of exposure based on the function defined below. Essentially, it gives a measure of how close a port is to a port that was hit by the tsunami, while taking into account the variation of wave height over the coast line.

What is evident is that the ports hit by the tsunami are clustered in one region of Japan, Tohoku, and to a lesser extent Kanto. We are principally interested in the response from ports that were not hit by the tsunami but regionally close enough to be able to absorb additional exports from the firms in the Tohoku and Kanto region. As further substitutes we find that ports in the Hokoriku and Tokai region may also be close enough

Figure 3: Tsunami hit and substitute ports



Note: Data on the height of the wave from the Japanese Ministry of Industry , the location of the earthquake from the US Geological Survey , exposure authors' calculations.

to be impacted. The northern island Hokkaido is a special case. As a separate island with no road links (there is a train tunnel from Aomori, at the north of Honshu, to Hakodate on Hokkaido) it is unlikely that its ports are affected by a substitution effect from the Tohoku region. Some ports of Hokkaido were exposed to the tsunami, but the recorded wave heights are minimal such that coastline barriers and storm protection may have proved sufficient to avoid severe destruction. We will explore this further in the empirical section.

The ports that were protected through natural bays or otherwise not directly facing the earthquake's epicentre turn out as substitutes with their degree varying with distance and the wave height of the ports that were struck. We find that the potential substitutes are mostly to be found in the Tohoku and Kanto regions, and further in Hokuriku and Tokai. The ports further south-east, starting from Kinki were likely too far away to be noticeable impacted and will henceforth be designated as the counterfactuals. Since we found no effect of either hit ports or from substitutes in Hokkaido these ports are designated as counter-factual as well, but we change this designation in the robustness analysis.

Hence we will exploit variation over time, ports and sectors, but not over origin and destination. Therefore we rewrite the equation as

$$\ln X_{kht} = \text{constant} + a \ln \mu_{kht} + b \ln \mu_{lht} + c \ln f_{kht} + d \ln f_{lht}$$

The tsunami is an event that can be tracked over time and geography (and sectors only in combination with the specific ports, further discussed below), while we can control for all other factors that affect determine a port's export pattern which are arguably uncorrelated with the Tsunami event. From this equation, port destruction will affect ports differently depending whether the shock is on the own port k, or to another, l. The only variables in the theoretical model that vary over k or l are the internal trade costs towards the ports and the fixed cost associated with each portμ_{ijk}, μ_{ijl}, f_{ijk} and f_{ijl}.

There is *a priori* no clear way to disentangle those two effects. On one hand infrastructure around ports and in some regions quite far inland was damaged or destroyed. In the immediate aftermath of the tsunami shortages in electricity or fuel may have been experienced by transporters. On the other hand, the destruction of ports probably dominates the effect on port exports, because alternative roads could likely be used with very little additional costs and the destruction inland was less severe than at the coast line. Therefore we need to assume that the outcome that we measure on trade is the sum of the effect that the tsunami had on the variable and the fixed costs, i.e. $a + c$ for the ports hit by the tsunami, and $b + d$ for the substitutes.

How does it matter for the research question? If we are interested in the effect of port *construction* or upgrades on exports we imagine that it it does not only affect the site of the port itself but also its direct surroundings. In order to make the port function efficiently additional road and supply routes may be part of the port construction. Therefore, in the case of port construction one would also expect that the local transport costs and the port's fixed costs are affected simultaneously. What we are estimating therefore is the average aggregate effect of such changes.

Although the comparative statics of the theoretical model are such that positive and negative shocks have the same elasticity, we do admit that analysing port destruction may not directly translate to answers on the effect of port upgrades. The destruction of ports does allow to look at the effect of major change in fixed costs that seems more suitable from an empirical point of view relative to a gradual infrastructure process. What also matters here is that ports were rebuild after the disaster and we take that period into account. So just as much as we can analyse the immediate impact, we can analyse the two years reconstruction phase to give backing on the mechanism that we have in mind.

The model we will estimate is

$$\ddot{y}_{k,h,t} = \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{1,\tau} \text{I}(\text{hit}_k) + \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{2,\tau} \text{I}(\text{sub}_k) + \epsilon_{k,h,t} \qquad (11)$$
$$k = 1, \ldots, 119;\ h = \text{variable},\ t = \text{jJan 2011},\ldots,\text{Dec 2012}$$

keeping with the notation of the theoretical model, k for port, h for sector and finally time t. The left hand side variable $\ddot{y}_{k,h,t}$ will be any trade variable of interest. The indicator functions $\mathrm{I}(\mathrm{hit}_k)$ and $\mathrm{I}(\mathrm{sub}_k)$ vary at the level of the port k. For each port we indicate whether it was hit by the tsunami on march 2011 in the first indicator, and whether it serves as a potential substitute for exports for the second indicator. The designation for substitute is defined as being located in one of the four regions where ports have the highest potential exposure (while not being hit by a tsunami themselves).

The parameters of interest are collected in the $\beta_{1,\tau}$'s and β_2's. Given the reduced form structural equation above we have the following relationship between the parameters that we estimate and those that come from the theoretical model: $\beta_{1,\tau} = a + c$ and $\beta_{2,\tau} = b + d$. In combination with the indicator functions $\mathrm{I}(\mathrm{hit}_{p,\tau})$ and $\mathrm{I}(\mathrm{sub}_{p,\tau})$, the estimated coefficients essentially indicate the evolution of the outcome variables over the 24 months time for the ports that are hit by the tsunami and those that we designated as potential exposed to substitution. Through this setup, the effect of interest is estimated as compared to all other ports that were neither hit by the tsunami nor close enough to the hit port to be potentially treated as substitute ports, in short 'others'. A port that is hit cannot at the same time function as a substitute. What we obtain through this setup is an average group effect for the two groups of ports relative to the rest. Since all the ports belonging to the groups of tsunami hit ports or substitute ports are shocked exactly at the same time (although possibly to different extents) there is no need for additional indicators for 'time-since-tsunami', the month dummies will be sufficient to observe the different patterns between the two groups relative to the counterfactual ports.

We will start with an analysis over aggregate exports without distinctions of sectors, effectively removing subscript h. In order gain to further insights we can disaggregate the trade flows over the sectors and we calculate the margins for each of the 2-digit sectors definitions.

As was indicated before, the ports are geographically clustered. Apart from that there might be other characteristics that are port specific but time constant (at least over the few years we are analysing) such as the characteristics of industry in the region that it services. Similarly, we like to control for sectoral effects (when analyses includes the sectoral dimension) and capture some effect of seasonality, which may be relevant for the monthly frequency of the data. Typically we would include a set of fixed effects that could be characterised as $\alpha_k + \gamma_h + \theta_{\mathrm{month}}$, or some interactive combination of these.[4]

Since the size of the shock from the earthquake and tsunami can be quite large and persistent for those ports that are hit, while potentially small for the ports that serve as substitute using a normal fixed effect procedure would filter out the variation that we want to explore. These fixed effects demean the variables using the entire time-span of the data. Since the period prior to the tsunami is shorter than the period after this

[4]These letters are not related to the ones in the theoretical model.

demeaning procedure could potentially filter out too much variation of interest from the period post-tsunami.

Instead, the outcome variable $\ddot{y}_{k,h,t}$ will be the pre-differenced transformation of $y_{k,h,t}$, where $y_{k,h,t}$ are the various measures for exports at the sectoral level, composed from an aggregation of detailed product categories. The pre-differencing comes in place of fixed effects in the regression. We subtract from the outcome variables a constant (over time) that is calculated as the average at the port-sector-month level using pre-2011 data. Therefore we chose instead to demean the outcome variables using only data from before the tsunami. With the calculation of the standard errors we make an adjustment in the degrees of freedom to correctly take into account this pre-differencing. The port-sector level demeans the outcome variables over the port size and specialisation, while the interaction with the month adjusts for potential seasonal effects.

We can control for the wide range of variation that will be evident among both the tsunami hit ports and the substitute. For the hit ports we have the recorded height of the wave that reached the individual ports, while for the substitute ports we can assume a function that approximates the potential exposure to additional exports from nearby ports. Here we assume the following structure for the measure of exposure,

$$\text{exposure}_k = \sum_{\kappa} \frac{\text{I}(\text{hit}_\kappa)\text{wave}_\kappa}{\text{dist}_{k,\kappa}}.$$

So for every port not hit by a tsunami we measure the distance to all ports hit by the tsunami. We assume that the effect diminishes with distance. However, the effect will increase with height of the wave that struck individual ports. Here we expect that the height of the weight is a measure of the destruction that took place and therefore the amount of exports that will be shifted from tsunami hit ports to other ports. We can only assume some functional forms on the exposure measure, rather than estimate it, but we can test the relevance by inspecting whether the exposure measure improves the inference of the coefficients relative to the model (11), which uses just an indicator function.

Using these measures we can augment model (11) to obtain

$$\ddot{y}_{k,h,t} = \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{1,\tau}\text{I}(\text{hit}_{k,h,\tau}) \times \text{wave}_k + \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{2,\tau}\text{I}(\text{sub}_{k,h,\tau}) \times \text{exposure}_{k,h} + \epsilon_{k,h,t}. \quad (12)$$

The issue with the substitute ports is that there are potentially two effects working on them. The substitution part will only play a role if firms are located near a port that was hit, but the firm itself was not affected by the disaster. In case the firm itself was affected by the tsunami, total production will have decreased and there will be no substitution taking place. We cannot control for this effect at this stage.

3.2 Data

Monthly export statistics for each customs office in Japan with details on destination, value, quantity, at the 9-digit (6-digit HS codes with 3-digit Japanese specific addition) product level was obtained from the Japanese Ministry of Trade website and is freely available. The values are represented as FOB. Customs are located both at sea and airports, we limit ourselves to seaports. Further information on the location of the ports was obtained the website http://www.searates.com. Road distances between ports were obtained from http://router.project-osrm.org which is based on OpenStreetMaps.

Besides the export value (by sector and port) we calculate the empirical margins of trade following Hummels and Klenow (2005). Using k for each (Japanese) port with reference port J representing the sum of all Japanese ports, h for sector, m for destination, I for the product set with individual product code i, and x for the export value, the margins are defined as,

$$\text{extensive margin: } EM_{k,h,m} = \frac{\sum_{i\in I_{k,h,m}} \sum_{k\in J} x_{k,m,i}}{\sum_{k\in J} \sum_{i\in I_{k,h,m}} x_{k,m,i}} \times 100,$$

$$\text{trade share: } TS_{k,h,m} = \frac{\sum_{i\in I_{h,m}} x_{k,m,i}}{\sum_{k\in J} \sum_{i\in I_{k,h,m}} x_{k,m,i}} \times 100,$$

$$\text{intensive margin: } IM_{k,h,m} = TS_{k,h,m}/EM_{k,h,m} = \frac{\sum_{i\in I_{h,m}} x_{k,m,i}}{\sum_{i\in I_{k,h,m}} \sum_{k\in J} x_{k,m,i}} \times 100.$$

The margins are calculated for each period independently resulting in a cross-port variation. The empirical intensive margin as defined here is the sum of the intensive margin and compositional margin from the theoretical model. Destination m can be either the rest of the world or country specific, similarly, sector h can be represented at various levels of detail including the least disaggregated level of a single sector. We will analyse our data with a single destination (the world), but over a single and 2-digit sectors.

As we are looking for a substitution effect we need to focus on those goods that were exported from ports that were hit by the tsunami. For this reason we restrict the sample to all goods that had non-zero exports during the entire year of 2010 from at least one of the ports that were hit in March 2011. This restricted sample represents 77% in terms of the total Japanese export value in 2010. We drop ports that have less than 100M (˜US$1M) of exports in 2010.

Density and distribution plots for the ports are presented in the appendix. These plots are informative for the inspection that the tsunami hit ports and substitution ports, although quite different in their characteristics, are not extraordinary relative to the entire collection of ports of Japan.

3.3 Descriptive statistics

Table 3 presents some descriptive statistics for the variables of interest over various groups, but without distinction of sectors for brevity. The full period includes the entire sample period from 2009 to 2014. The pre- and post-periods present the data for Dec 2010 - Feb 2011, and Mar 2011 - Apr 2011 respectively, with the last column presenting a simple t-test on the means. As is evident from the extensive margin, trade share and number of varieties, the tsunami-hit ports are considerably smaller than the national average, while the substitute, given that these include the ports around Tokyo are considerably larger than the average. Only for the trade share of tsunami hit ports does the t-test indicate a significant drop in exports at the 5% level. What this means is mainly that the data series have a large variation and unconditional tests are not able to pick up the major shock, not even for the export value of the tsunami hit ports. This is interesting because it is clear that these ports were severely affected.

3.4 Results

We estimate the above models on various export measures, namely, intensive margin (which includes the compositional margin), extensive margin, log(export value) and trade share. Each of these measures are taken at the sector level for each port. Since we recover 48 coefficients for each outcome variable (the 24 months for tsunami hit and substitute ports) we present results of the coefficients graphically as a time plot. The relatively long time-span of analysis allows to observe a time patterns that would be difficult to discern when focussing only on the immediate aftermath of the tsunami. We provide confidence bands using both robust standard errors and clustered standard errors at the regional level. The cluster-level would relate specifically to the suspicion that ports within the same region will be supplied by firms that are similarly affected by the disaster and cause correlation between those firms, but not so when moving further away to the regions.

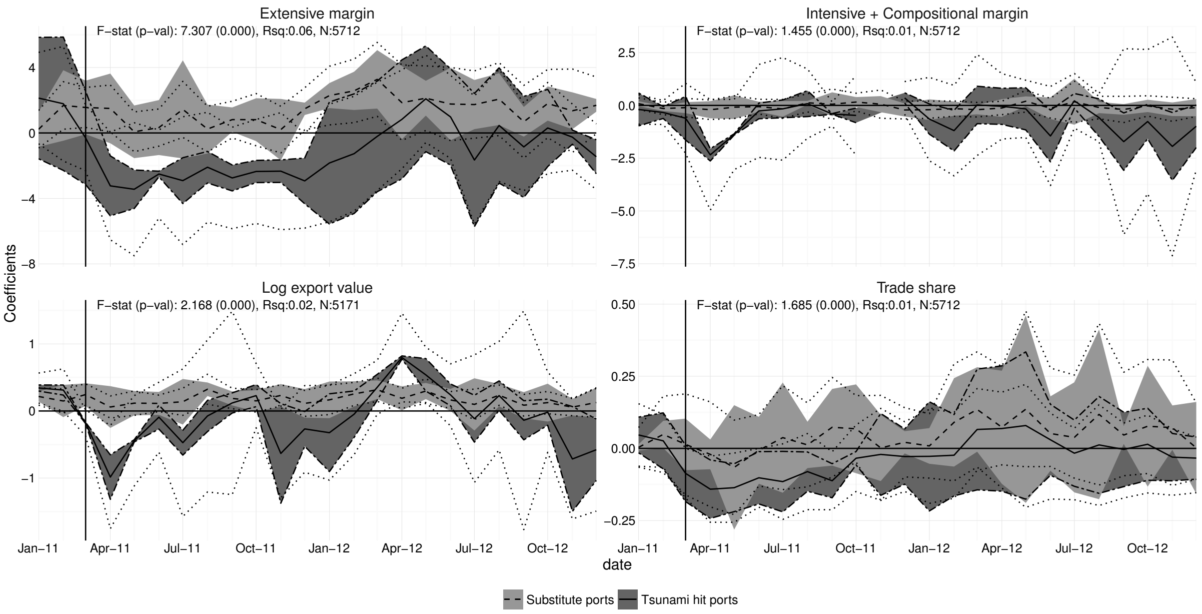
Figure 4 presents the first results based on model (11) and margins based on exports without sector definitions. On the horizontal axes time is indicated from January 2011 to December 2012. The vertical black line indicates the month of March 2011, the first month in which the data should show an effect from the tsunami. The horizontal zero-axis is accentuated to aid on the inspection on whether the two groups of ports exhibit a statistically significant different pattern from the counter-factual ports. In this way the plots allow for a range of comparisons, notably,

1. for each group (tsunami hit ports and substitutes) relative to the counter factual at every point in time while having demeaned all observations by the 2009-2010 data,
2. relative to the two months before the tsunami, and
3. relative to each other.

Table 3: Descriptive Statistics

	measure	group	N.customs	full.mean	full.sd	mean.pre	sd.pre	mean.post	sd.post	test
1	EM	Other	77	12.57	16.95	12.14	17.08	12.79	17.11	0.68
2	EM	Tsunami hit	15	8.06	9	8.99	10.13	6.24	7.14	0.14
3	EM	Substitute	27	26.93	25.07	25.91	25.3	26.56	24.95	0.87
4	EM	all	119	15.26	19.51	14.87	19.55	15.09	19.46	0.88
5	IM	Other	77	3.85	6.87	3.58	4.62	4.3	8.17	0.25
6	IM	Tsunami hit	15	3.32	5.02	3.07	3.65	2.46	3.85	0.44
7	IM	Substitute	27	4.33	5.67	4.31	5.37	4.16	4.95	0.85
8	IM	all	119	3.89	6.41	3.69	4.69	4.03	7.13	0.44
9	lValue	Other	77	14.89	2.54	14.82	2.7	14.97	2.6	0.57
10	lValue	Tsunami hit	15	14.67	2.2	14.77	2.04	14.39	1.89	0.39
11	lValue	Substitute	27	16.5	2.23	16.47	2.13	16.47	2.21	0.99
12	lValue	all	119	15.24	2.53	15.19	2.59	15.25	2.53	0.76
13	nvar	Other	77	407.69	792.1	408.31	799.54	407.74	797.7	0.99
14	nvar	Tsunami hit	15	201.04	239.21	198.51	233.23	187.82	219.98	0.82
15	nvar	Substitute	27	966.61	1278.9	944.27	1270.14	943.79	1264.12	1
16	nvar	all	119	508.45	922.09	503.47	918.75	501.65	915.88	0.98
17	TS	Other	77	0.51	1.34	0.53	1.37	0.58	1.57	0.71
18	TS	Tsunami hit	15	0.19	0.25	0.22	0.28	0.11	0.16	0.03
19	TS	Substitute	27	2.14	4.34	2.08	4.36	1.99	4.15	0.89
20	TS	all	119	0.84	2.44	0.84	2.44	0.84	2.43	1

Figure 4: Aggregate margins of trade, model (11)



For the intensive margin of tsunami hit ports, the coefficient of November 2011 is omitted as it was evidently outside of what could be expected indicating a point estimate of +9. Each plot represents one regression and some statistics regarding the model are indicated. The F-statistic is calculated as the difference between the estimated model and the projected variable with no additional regressors. The F-statistic and standard errors take a degrees of freedom adjustment for the projection/demeaning method.

While a time pattern appears in the various plots we have not employed a smoothing technique or inter-month time dependence to gain some efficiency out of the time patterns. Every coefficient is calculated as the average difference relative to the counter-factual for a given month. Confidence intervals at the 95% significance levels are indicated by the shaded areas for the clustered standard errors, while robust standard errors are indicated by the dotted lines (the shaded areas for the tsunami hit coefficients is lined a dashed pattern to aid inspections when the two area falls behind the shaded are of the substitution coefficients). The dramatic shock of the tsunami for the tsunami hit ports is clearly visible. The drop is bigger for April 2011 relative to March as it accounts for the fact that exports were normal during the month until the earthquake of 11 March. The recovery took a few months, but there is a difference between the various measures. While the log export value appears to recover within a few months, it falls back again and remains relatively volatile, the extensive margin takes longer to recover and only at the start of 2012 become largely indistinguishable from zero and the substitute ports. The intensive margins shows overall much less variation than the extensive margin, with a similarly quick recovery. The trade share appears recovered by the start of 2012 in line with the mathematical relation between the three margins.

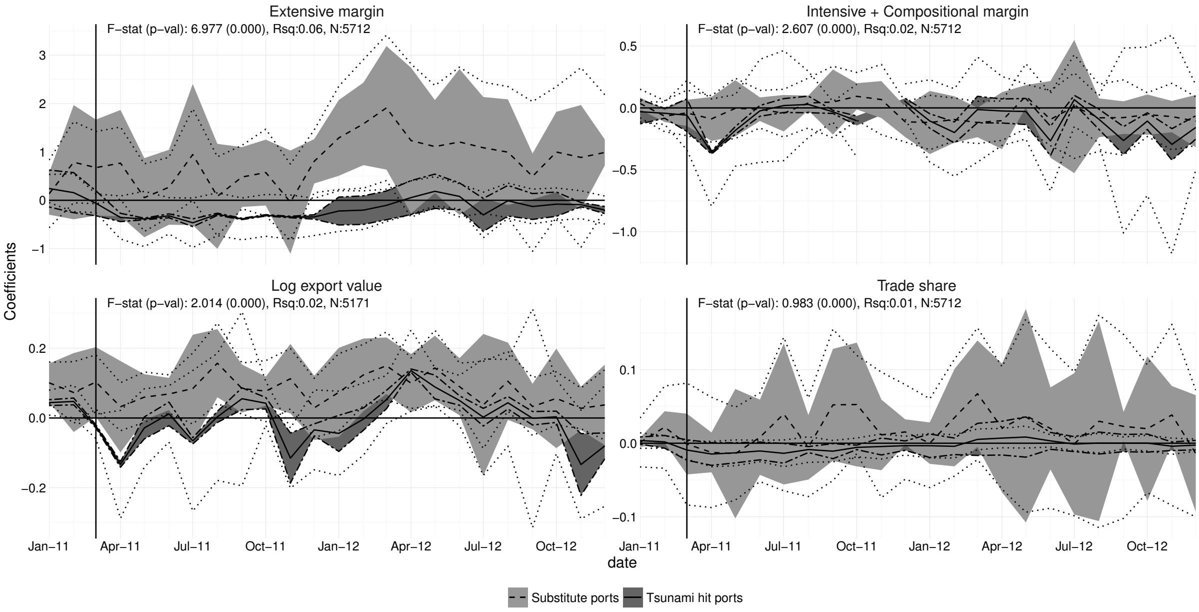
Focusing on the substitute ports we note that any response is much less dramatic relative to the fall of the tsunami hit ports. This is overall not surprising. As was evident from the descriptive statistics there are more substitute ports and each of these are generally larger relative to the substitute ports. If there is any trade substitution the effect will be smaller than the shock from the destructed ports. Still we find that the extensive margin receives a significant bump at the same time as the the tsunami hit ports start to return to pre-tsunami levels. For the intensive margin the response is much smaller overall and largely indistinguishable from zero. For the log export value we find a significant increase from the summer of 2011 to the summer of 2012. Finally for the trade share, the point estimates suggest a sizeable and persistent bump for substitute ports, but the standard errors around the point estimates suggest a large variation within the group.

The clustered standard errors lie generally within the dotted lines that indicates the robust errors. Since we know that the ports hit by the tsunami were dramatically affected, it appears that the robust standard errors are too conservative, but the difference between the two is minimal for the substitute ports. The pre-differencing method also works well to center the coefficients around zero generally before March 2011. One can also observe here that using fixed effects for the entire time-period would likely make it harder to observe the persistent effect from the tsunami, which is something that we will inspect in the next section.

The size of the effects can directly be read from the vertical axes. We can see that the negative shock for the tsunami hit ports were around 3 percentage points decline while there is a 2 percentage points increase for the substitutes at their respective peaks. Given the average of 8 for the Tsunami hit ports this means a 37% decline. For the substitute ports the effect is smaller, presenting about a 10% increase. The log value indicates a dramatic drop in exports value, suggesting a complete closure of these ports for the first few months after the distaster, which is otherwise not surprising. What is interesting is the relatively quick recovery, while the substitute ports on average at their peaks would have gained 30% additional exports. However, the confidence bands are rather wide suggesting a wide variation of experiences.

From this first set of results we can gain further insights by varying our analysis over various direction. Firstly we will show model (12) using the same margins. Results are presented in Figure (5). There are two major differences, 1) the interpretation for the coefficients now takes into account the unit of measurement, which is in meters of the wave height for the tsunami hit ports and exposure in terms of wave height meters/distance in km $\times$ 10 (using tens of kilometers scales the measures to comparable amplitudes), 2) the confidence interval for the tsunami hit ports are much tighter (especially for the extensive margin), but for the substitute ports the precision of the estimates appears not majorly affected. As before we find the most significant effects for the extensive margin

Figure 5: Aggregate margins of trade, model (12)



Note: The horizontal axes now take into account the unit of measurement of the right hand side variables, which is wave height in meters for the tsunami hit ports and the exposure measure as wave/distance (m/km) for the substitute ports. The coefficients for the latter have been multiplied by 10 for readability.

and the log export value, while the intensive margin and trade share show no statistically significant result.

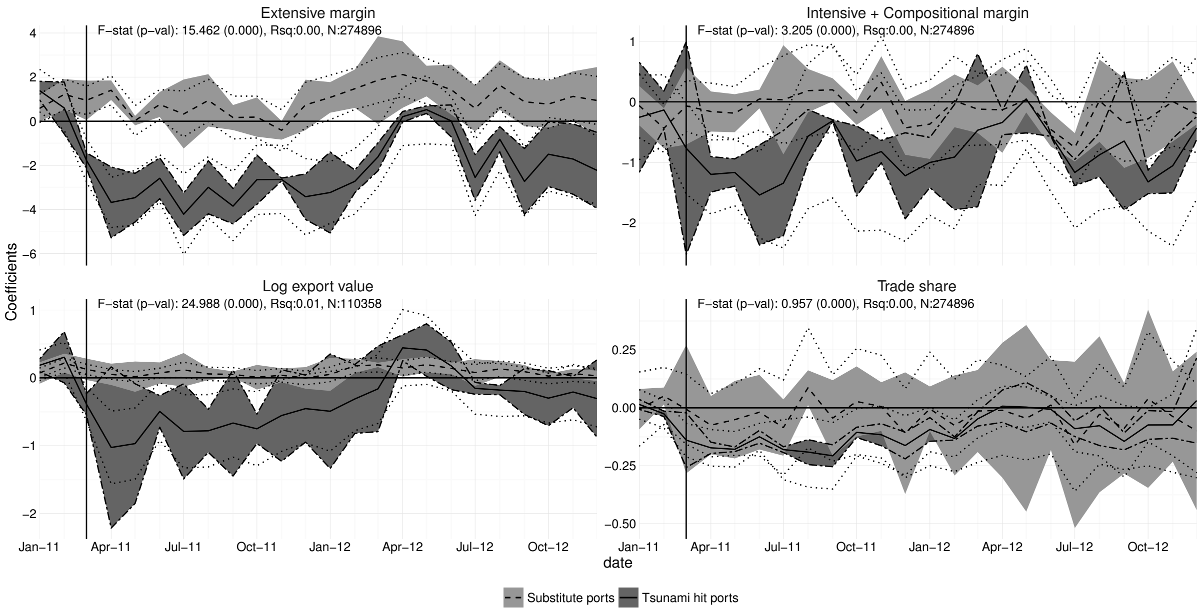
We next turn to the analysis at the level of two-digit sectors. The main benefit here is that the outcome variables are demeaned at the sectoral level. At the same time we can keep track of the sectors in which the tsunami hit ports were exporting in 2010, rather than defining this at the product level. Given this additional level of detail the estimates should be more precisely estimated.[5] For substitute ports we can now additionally control for the difference between sectors that were hit by tsunami and those that were not. For instance, for a certain port, one sector my be 'treated' since a tsunami hit port was exporting in the same sector, but another may not be treated and therefore belongs to the group of counterfactuals. Note that we greatly increase the number of observations in this way as every port is now represented through a double digit number of sectors. In this case the cluster procedure becomes even more relevant, but clustering at the regional level is still appropriate as it nests a clustering procedure at the port level.

The plots in Figure (6) indicate that the sectoral perspective does help to gain efficiency in the estimation. While the patterns are generally similar, the precision of the estimates is better and the month-to-month volatility of the coefficients has decreased, but the amplitude of the regressors has generally increased. From these plots it is now also clearer that shock has a similarly persistent effect for the log of the export value as it

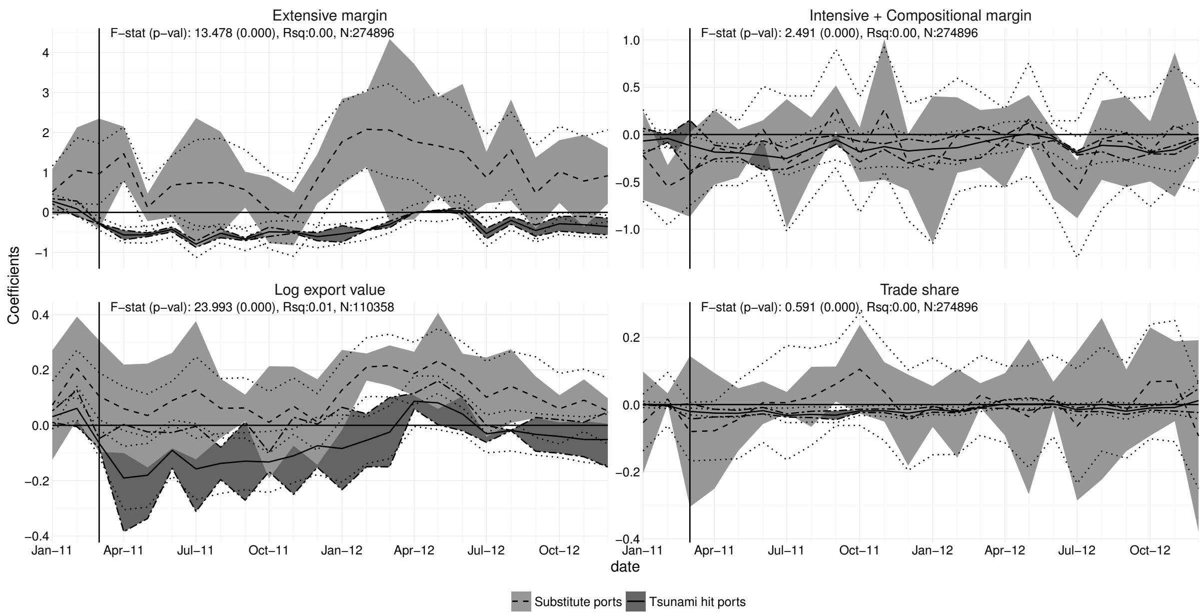
[5] *A priori* there is little reason to think why some sectors would be structurally more or less affected by the tsunami at the port level.

Figure 6: Sector margins of trade

(a) model (11)



(b) model (12)



has for the extensive margin. While for tsunami hit ports the estimated effect on the intensive margin and the trade share appears to have decreased, for substitute ports the estimates suggest that the average effect is around zero. Model (12) helps to increase the precision of the coefficients on all measures for the tsunami hit ports but it does not do so for the substitute ports. Specifically for the effect on log export value it rescales the effect making it evident that there is a significant bump from the start of 2012 that coincides with a recovery of the tsunami hit ports, and the pattern is similar to the one observed for the extensive margin.

The combination of these results all point to effects that are in line with the theoretical model. The tsunami hit ports observe a significant decline in exports, that this can be decomposed in to a extensive margin and intensive-compositional margin, where the major part of the effect goes through the former rather than the latter. For the substitute ports we are able to observe the opposite effect, but the effect is less precisely estimated. For the substitute ports therefore the effect is evident in the log export value and extensive margin rather than in the intensive margin or trade share. Moreover, the substitution effect appears stronger during the recovery face rather than as an immediate response to the disaster.

3.5 Robustness

Figure 7 presents some variations on the regression and sample. For brevity only the extensive margin and log export value are reported. The first two rows present the results where instead of pre-differencing we use a combination of fixed effects to demean the data. Both variations of models (11) and (12) are reported. The variation can algebraically be presented as,

$$y_{k,h,t} = \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{1,\tau} \mathrm{I}(\text{hit}_k) + \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{2,\tau} \mathrm{I}(\text{sub}_k) + \alpha_k + \theta_{\text{month}} + \theta_{\text{year}} + \epsilon_{k,h,t}, \quad (11')$$

$$\begin{aligned} y_{k,h,t} = & \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{1,\tau} \mathrm{I}(\text{hit}_{k,h,\tau}) \times \text{wave}_k + \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{2,\tau} \mathrm{I}(\text{sub}_{k,h,\tau}) \times \text{exposure}_{k,h} \\ & + \alpha_k + \theta_{\text{month}} + \theta_{\text{year}} + \epsilon_{k,h,t}, \quad (12') \\ & k = 1, \ldots, 119;\ h = 1,\ t = \text{jan 2009}, \ldots, \text{Dec 2015}. \end{aligned}$$

Notice that the dependent variables have changed to non-transformed measures, while the fixed effects are introduced for the port, month and year level. While models (11) and (12) are in fact using an interaction method of custom with month, in this case we are adding them additively.

What is evident from the first two rows of plots in Figure 7 is that while the shock on tsunami hit ports is still evident, the effect disappears much quicker, while for substitute ports the variation seems perfectly demeaned that no pattern is noticeable. The bump at the start of 2012 is however still visible and statistically significant.

The third row adds the ports in Hokkaido as treated, either as ports hit by the Tsunami hit or substitute, as indicated at the map of Figure 3. The main effect is that while the point estimates have not changed greatly, the standard errors have become much wider for the tsunami hit ports, especially the ones based on the clustering. These results indicate that distance between the epicentre of the earthquake and the ports in Hokkaido was probably large enough to avoid major damage being done to these ports, making their inclusion in the regression a factor of noise.

The last row handles the treated sectors at the port level differently. Whereas in Figure (6a) we treated sectors as treated or not for a certain point (given that the port was in one of the four regions around the tsunami hit area), in Figure (12c) we indicate treatment at the port level rather than the sector. This variation gives practically identical results relative to those presented in Figure 6a.

In the appendix we present further variations in our setup. We present results for each of the four regions that contain ports that are substitutes or hit, or both. These results indicate that it is not one region that drives the result but the effect is present for all regions although estimating parameters for each region separately results in a loss of precision.

We vary the distance at which ports are assumed to be exposed to treatment. This variation matters for the size of the estimated coefficients but the general pattern is similar to what we have shown so far.

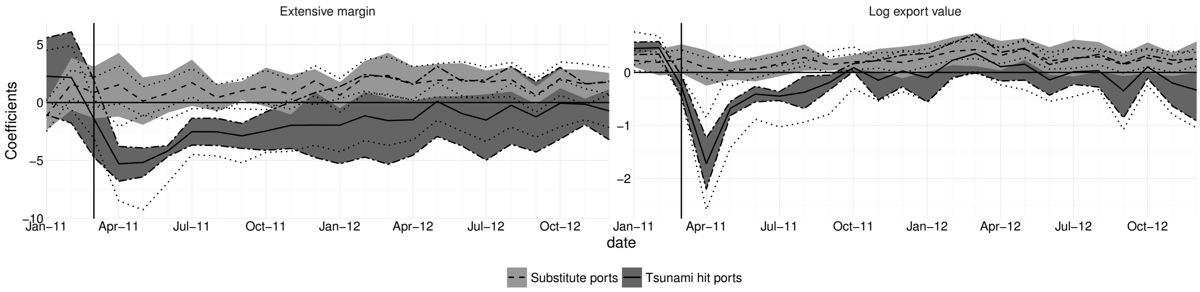
3.6 Discussion

Although the results thus far indicate that substitute ports have experienced the opposite effect in terms of their exports since the aftermath of the tsunami relative to the ports that were direct struck by the tsunami, the effect also appears to be delayed rather than immediate. The bump visible around the first few months of 2012 for substitution ports coincides with recovery of the tsunami hit ports. One could therefore argue that the substitute ports benefit from a reconstruction boom rather than from an absorption of exports from other ports.

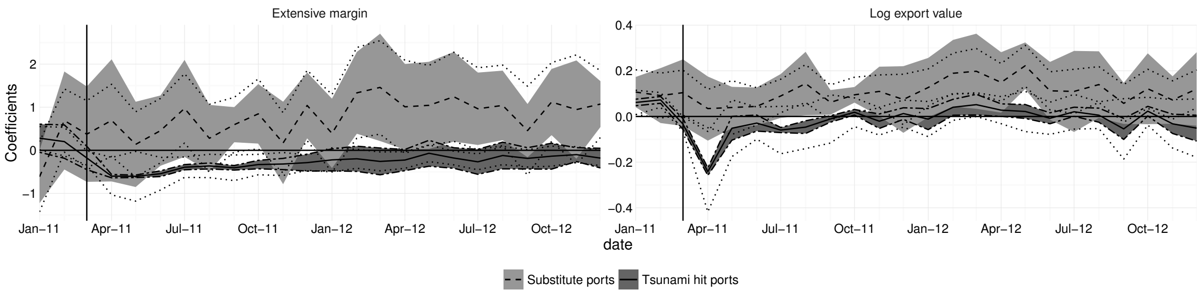
We believe the more plausible explanation is that firms were also affected by the tsunami, especially those located in the coastal towns. In the immediate aftermath of the tsunami those ports towns that were hit by the tsunami had both a destruction in ports as well as the surrounding local firms. The images of waves flushing away houses and cars far land-inwards are evidence of this, even if such effects may have been limited to a small number of towns. As the debris was cleaned and life normalized firms had a choice to make: through which port to export. At this moment in time we find that exports at the

Figure 7: Robustness analysis

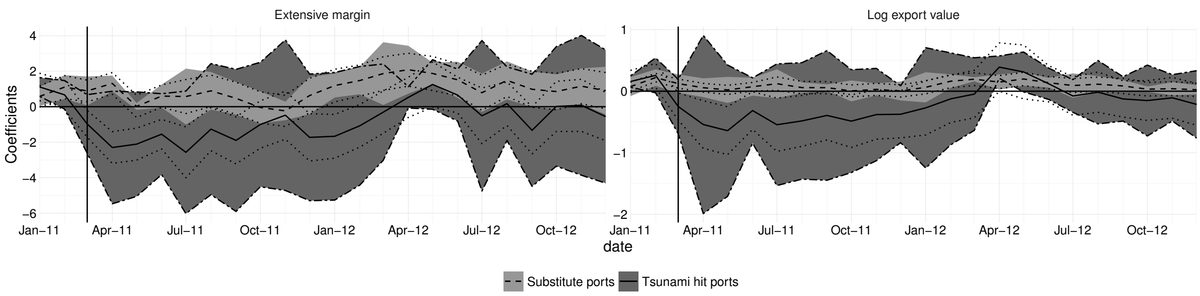
(a) aggregate, model (11) with fixed effects



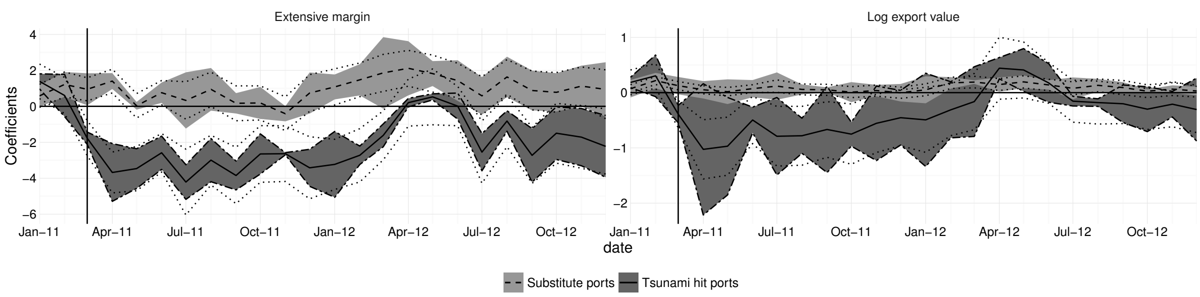
(b) aggregate - model (12), with fixed effects



(c) sector margins, model (11), with Hokkaido as treated



(d) sector margins, model (11), with all sectors



regional level are increasing again, and that those ports that were not hit are benefiting from this by absorbing some of the recovered activity. When ports hit by the tsunami are further repaired firms could re-optimise their decision and switch back to a closer port as the costs of exporting through these ports have further declined. This is in line with the theoretical model and our main research question: a decline of local transport costs will draw away exports from neighbouring ports, we do not find in our time frame of analysis that the two combined sets of ports in aggregate gain over and above their counterfactual.

4 Conclusion

In this paper, we build a novel model with multiple ports and heterogenous firms. Exporting requires local transportation costs and port specific fixed costs as well as international bilateral trade costs. A port is characterized due to its comparative advantage between these two port specific costs with respect to the others. Multiple ports are in action in equilibrium in the presence of port comparative advantage. We then establish a gravity equation with multiple ports and show gravity distortion due to heterogenous firm is conditional on both form of internal trade costs. We analytically present comparative statistics results for each margin of trade and show export switching from one port to the another can be accounted for exogenous variation in both port specific local transportation costs and port specific fixed export costs. Finally, we test the prediction of the model with Japanese custom data and find a supportive evidence for a port substitution following the 2011 Great Japanese Earthquake.

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A Proof of Proposition 1

First we look the ranking condition of cutoff productivity levels. From (4) and taking the ratio of ZCP of two ports k and s with $k > s$,

$$\left(\frac{\overline{\varphi}_{ijs}}{\overline{\varphi}_{ijk}}\right)^{\sigma-1} = \left(\frac{\mu_{ijk}}{\mu_{ijs}}\right)^{1-\sigma} \frac{f_{ijs}}{f_{ijk}}.$$

We have $\overline{\varphi}_{ijk} < \overline{\varphi}_{ijs}$ when $f_{ijs}/f_{ijk} > (\mu_{ijs}/\mu_{ijk})^{1-\sigma}$. Also dividing (6) by profits for port s,

$$\left(\frac{\overline{\varphi}_{ijks}}{\overline{\varphi}_{ijs}}\right)^{\sigma-1} = \frac{\mu_{ijs}^{-(\sigma-1)}}{\mu_{ijs}^{-(\sigma-1)} - \mu_{ijk}^{-(\sigma-1)}} \left(\frac{f_{ijs} - f_{ijk}}{f_{ijs}}\right) = \frac{1 - \frac{f_{ijk}}{f_{ijs}}}{1 - \left(\frac{\mu_{ijk}}{\mu_{ijs}}\right)^{1-\sigma}}$$

Thus when $f_{ijs}/f_{ijk} > (\mu_{ijs}/\mu_{ijk})^{1-\sigma}$, we have $\overline{\varphi}_{ijs} < \overline{\varphi}_{ijks}$ simultaneously.

Next we look for the condition with which a marginal increase in productivity $\varphi^{\sigma-1}$ induces higher dividends for port s than port k. Namely,

$$\frac{\partial d_{ijs}(\varphi)}{\partial \varphi^{\sigma-1}} > \frac{\partial d_{ijk}(\varphi)}{\partial \varphi^{\sigma-1}} \tag{13}$$

From (3) and (2), we can express profits in exporting from port k as

$$d_{ijk}(\varphi) = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\mu_{ijk}\tau_{ij}}{\varphi q_{ij}Z_iP_j}\right)^{1-\sigma}\alpha Y_j - f_{ijk}$$

The similar expression holds for port s. Deriving these expressions with respect to $\varphi^{\sigma-1}$ for each port, we have $(\mu_{ijk}/\mu_{ijs})^{\sigma-1} > 1$ so that (13) holds. On the other hand, when $(\mu_{ijk}/\mu_{ijs})^{\sigma-1} < 1$, for a marginal rise in productivity level, exporters prefer to export from port k. In such a case, all firms prefer to export from port k.

Finally, having established $C(K_n, 2)$ number of even profit cutoff productivity levels for any combination of two ports, provided the ranking of zero profit cutoff productivity levels for each port as (5), the firm with φ eventually chooses to export from one specific port k^* that maximizes its exporting profits $d_{ijk^*}(\varphi)$, specifically by solving the following problem.

$$\max_{d_{ijk^*}(\varphi)}\left[d_{ijK_n}(\varphi), d_{ijK_n-1}(\varphi), ..., d_{ij2}(\varphi), d_{ij1}(\varphi)\right]$$

Together with the specific preference of firms with respect to exporting port as defined previously, the above condition establishes the proposition 1.

B additional statistics

B.1 statistics on ports

B.2 Distributions

Figure 8 gives a representation of the distributions of the four key variables, grouped as tsunami hit ports, substitutes and other. The plots are based calculated using the average margins or values over 2009-2010 (i.e. pre-tsunami). The density plots are calculated for each group separately, allowing to see the range of the available observations for each group. What is evident is that the substitute ports are relatively larger in terms of export value, and their extensive and intensive margin. The substitute ports are skewed towards the low end of the trade margins, but in terms of export value appear centred relative to the other ports.

Figure 8: Density plot - port level

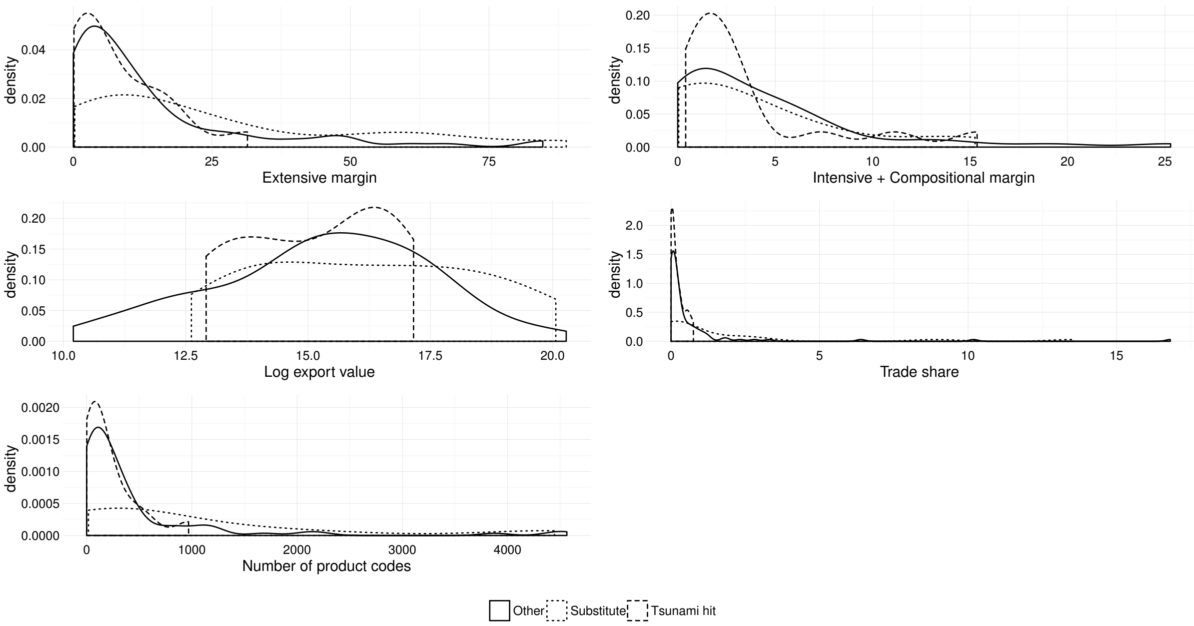
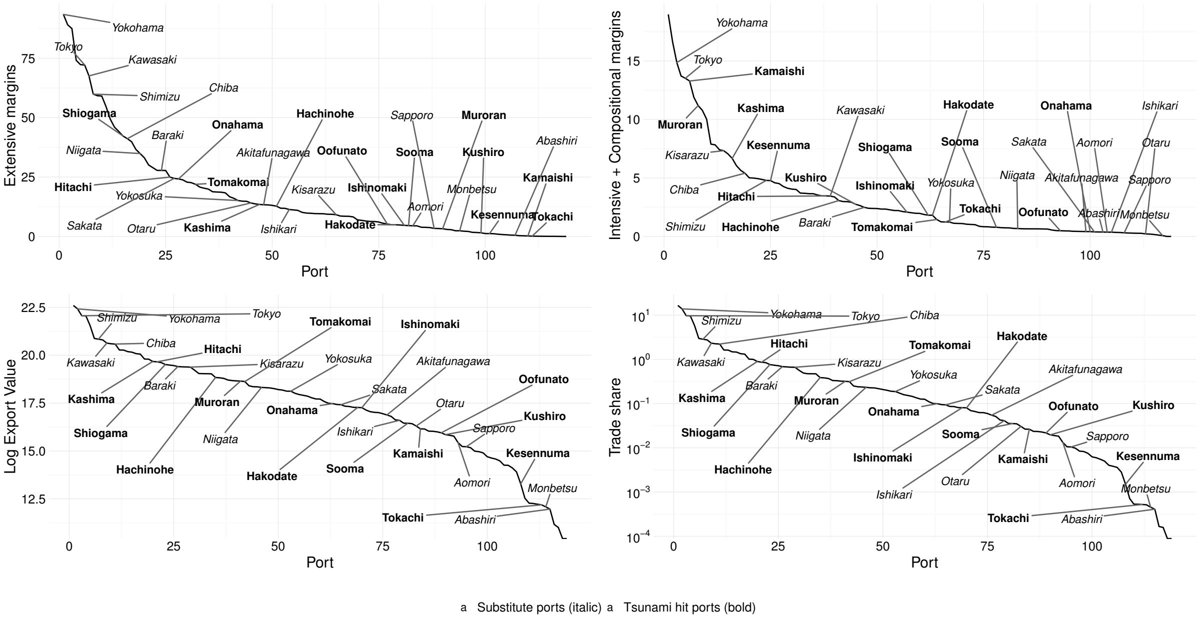


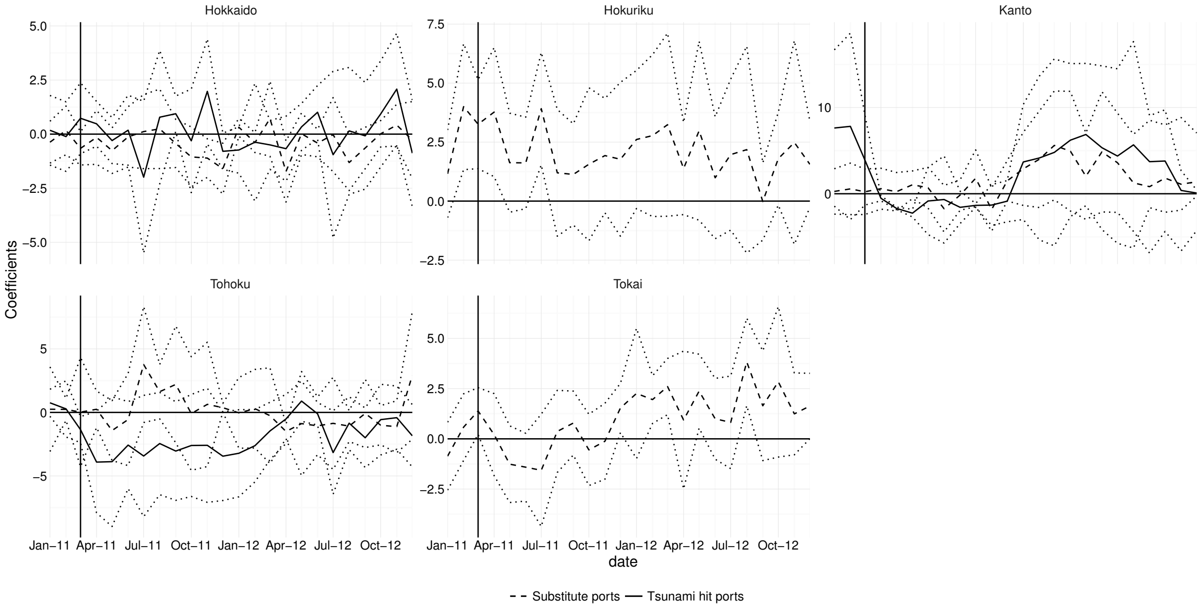
Figure 9: Ports ranked by trade measures (2010)



B.3 Additional regression results

Figure 10: results by region, aggregate, model (11)

(a) Extensive margins



(b) Log Export value

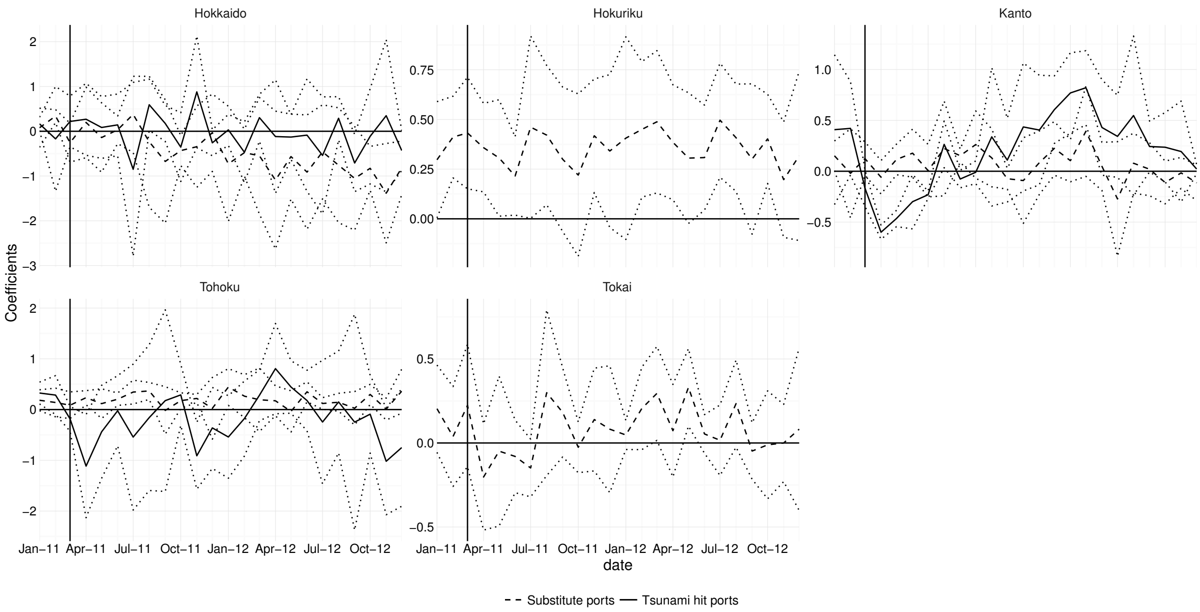
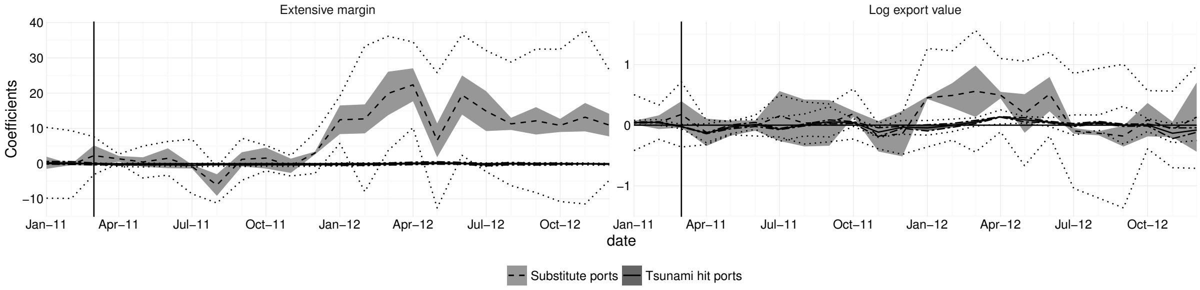
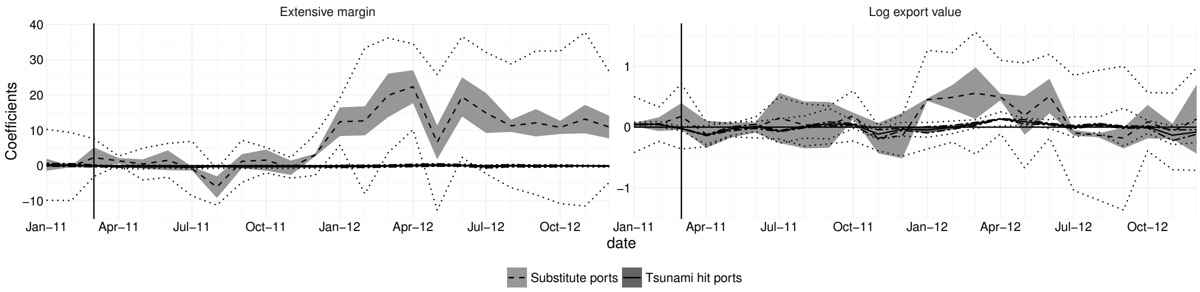


Figure 11: model (12)

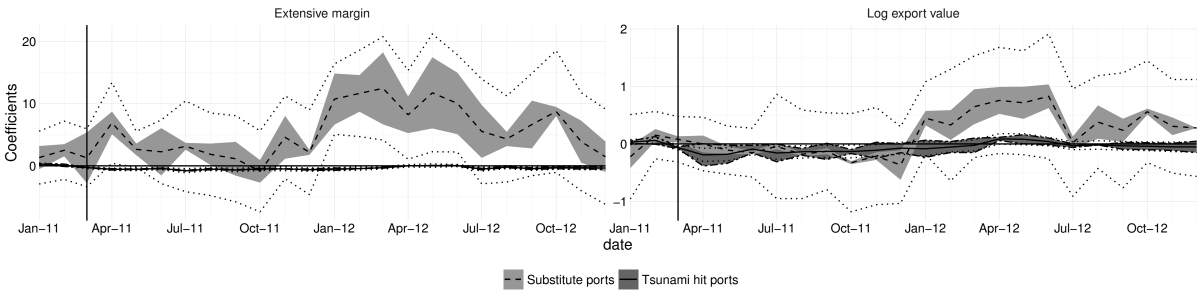
(a) Aggregate, exposure capped at 100km



(b) Aggregate, exposure capped at 500km



(c) 2d sectors, exposure capped at 100km



(d) 2d sectors, exposure capped at 500km

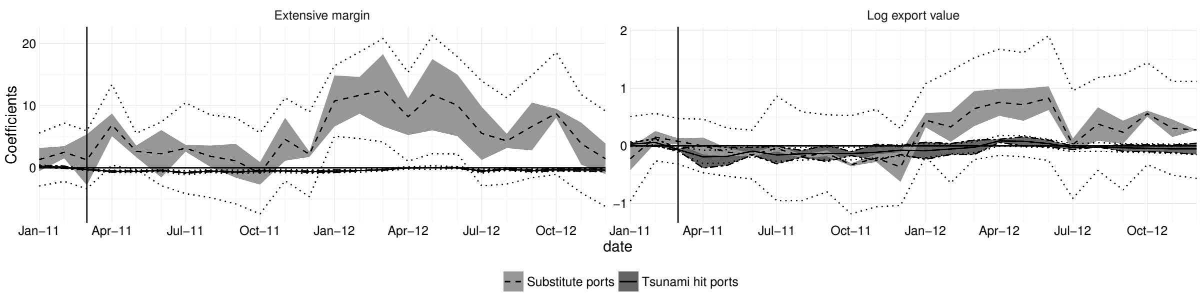
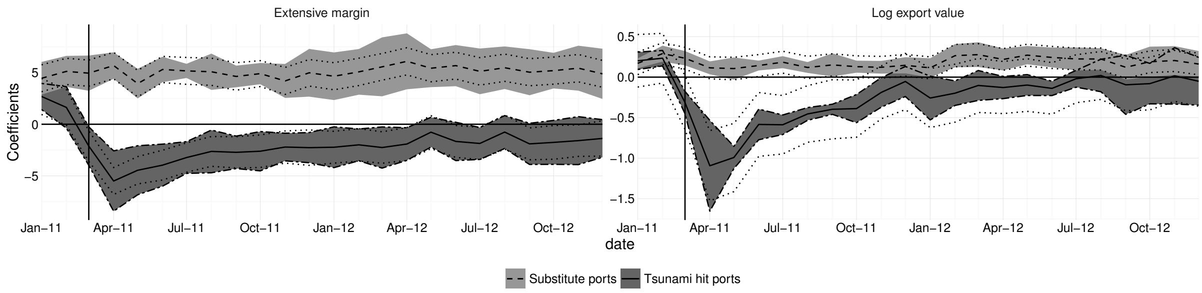
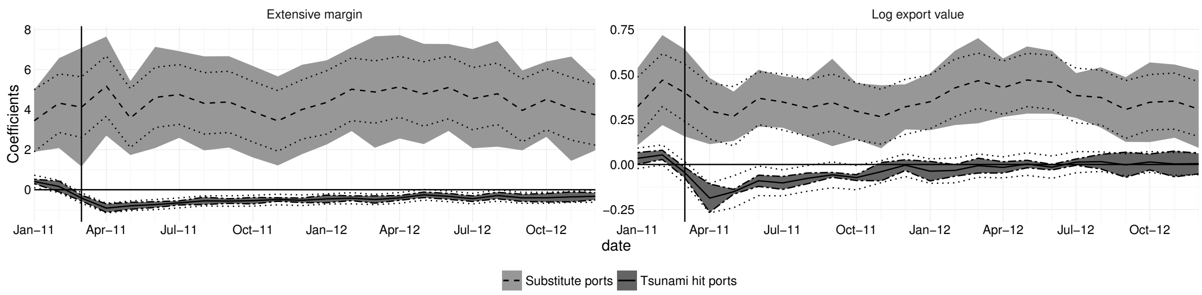


Figure 12: Counter parts Figure 7

(a) 2d sectors, model (11) with fixed effects



(b) 2d sectors, model (12), with fixed effects



(c) Aggregate, model (11), with Hokkaido as treated